The Principles of Vacuum And Clinical Application in the Hospital Environment

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This monograph has been written to provide caregivers an overview of the use of medical suction and vacuum equipment operation in the hospital environment. Ohio Medical recognizes that there are differences in opinion among clinicians regarding both specific suction techniques and the appropriate levels of negative pressure that should be used for various suction applications. Although recommendations made in this monograph are based on published reports in the literature, standard practices, and manufacturers' guidelines, clinicians should always consult written policies and procedures of their hospitals.

INTRODUCTION

In most modern hospitals, vacuum is available from wall outlets located throughout the building. Other sources of vacuum include electric pumps, gas-powered venturi suction units, and mechanical devices, such as hand pumps and wound drainage systems. The major source of vacuum in hospitals is a pump in the basement of the building. By emptying a receiver or reservoir tank, the pump creates a vacuum that can be delivered through connecting pipes to wall outlets in patient care areas and hospital departments (Figure 1). When the vacuum pressure falls to a predetermined level, a switch engages the pump to restore vacuum pressure; when the vacuum builds back up, the switch disengages and no further vacuum is created. Generally the pump is set to begin operation when the vacuum level of the system drops to 19 inHg (483 mmHg) and ceases operation when the level reaches 25 inHg (635 mmHg).

In most hospitals, a duplex pump system is used for safety; each pump is capable of maintaining minimum vacuum levels. A duplex system allows for periodic shut-down of each pump for service and repairs and also provides a backup source for negative pressure, should one of the pumps fail to operate properly.

Hospital Duplex Vacuum Pump and Receiver

Figure 1

Suction equipment can be connected to the vacuum outlet which can be used for procedures such as airway suctioning; gastrointestinal decompression, pleural suctioning, and suctioning during operative procedures.

BASIC VACUUM

The term vacuum can be defined in two ways: as a space empty of matter, or a space in which the pressure is significantly lower than atmospheric pressure. It is the lower pressure term that has clinical relevance. In fact, for clinical use, vacuum can be more simply defined as negative pressure. Suction is defined as the application of negative pressure to create movement of air, liquids or solids.

If a vacuum pump that is attached to a closed rigid tank, removes one-half of the tank's gaseous contents, then the pressure within the tank will also be reduced by one-half. As the remaining gas (or air) expands to occupy the full tank volume, a sub-atmospheric pressure or vacuum is produced. Gas movement is dependent on pressure gradients. If a small opening is made in the tank so that it is open to the atmosphere, the air outside the tank at atmospheric (higher) pressure will rush in to the tank which has a sub-atmospheric (lower-negative) pressure. This movement of air into the tank causes vacuum (suction). Suction, causing flows toward the tank will continue until the air pressures inside and outside the tank are the same.

The forcefulness of the suction is determined primarily by the degree of the negative pressure being applied. Pressures are measured by gauge pressure, which is the pressure above or below ambient atmospheric pressure. The atmospheric pressure that indicates as zero on ordinary pressure gauges is 760 mmHg, which is normal pressure at sea level. Negative pressure is therefore, defined as pressure less than atmospheric or pressure less than zero (atmospheric) on the pressure gauge (Figure 2).

Clinical Vacuum Gauge
Figure 2

MEASURING VACUUM PRESSURE

Negative pressure is a measure of the amount of vacuum force exerted to raise a column of liquid to a certain height. Negative pressure is usually measured by the height of either a mercury or water column in inches, centimeters or millimeters (cm H_2O, inHg, mmHg). Since both water and mercury columns are used to measure negative pressures and standardize and calibrate mechanical vacuum gauges, gauge pressure may be expressed in both mercury and water units. Since water is 13.6 times less dense than mercury, gauges calibrated to water columns generally are limited to a smaller range of pressure than those calibrated to mercury columns.

Appendix B contains a table of conversion factors. One inch of mercury negative pressure is the amount of vacuum required to lift mercury up a column one inch or, expressed metrically, up 25.4 millimeters (1 inHg negative pressure = 25.4 mmHg negative pressure). The same amount of vacuum will lift water up a column to a height of 13.6 inches (1 inHg negative pressure = 13.6 in H_2O negative pressure) or 34.5 centimeters (1 inHg negative pressure = 34.5 cm H_20 negative pressure).

1 inch mercury = 25.4 mmHg
13.6 in H_20
34.5 cm H_20

Inches of mercury is the term commonly used to measure hospital wall system negative pressures. In patient care environments, negative pressures are usually measured in millimeters of mercury or centimeters of water (Figure 3).

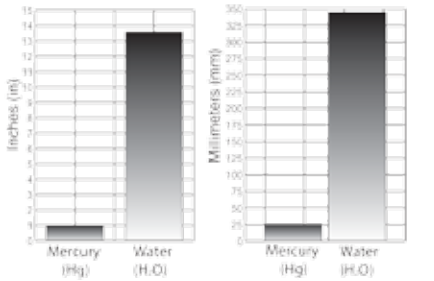
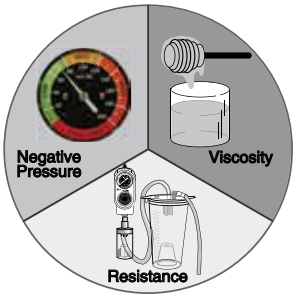


Figure 3

THE RATE OF FLOW

A dynamic in medical suctioning is the flow rate at which air or liquid is removed through the system and from the patient. The flow rate is determined by three factors:

1. The amount of negative pressure produced by the vacuum source, up to a maximum value.
2. The resistance of the suction system, primarily determined by the diameter of the suction catheter and also due to the connecting tubing and collection canister.
3. The viscosity of the matter being suctioned (Figure 4).



Flow Rate Factors
Figure 4

In clinical use, equipment consisting of collection canister, suction tubing and catheter is connected to a suction regulator that is attached to a vacuum source. As the regulator is adjusted, the vacuum is transmitted from the source through the equipment to the end of the suction catheter. Before there can be suction at the tip of the catheter, there must be a vacuum in the collection canister.

If the negative pressure in the collection canister is increased (by adjusting the regulator), the flow rate of air or gas through the distal tube will also increase. Maximum flowrate is limited by the total resistance within the system (regulator, tubing, canister, catheter); therefore, at a certain vacuum level, no additional flow is gained by further increasing the vacuum pressure). As flow increases there is a gradual change from laminar (smooth/streamline) flow to turbulent flow. In most circumstances, once turbulence occurs, the negative pressure in the collection canister must be increased nearly four times to double the flow rate through the equipment.

The clinician must be cautious when determining the amount of negative pressure applied to the patient. **The minimum amount of negative pressure necessary to accomplish the suctioning procedure should be used.** When additional flow is necessary, changes in other suction variables, such as tubing length and diameter should be considered before increasing negative pressure.

Besides the negative pressure, the resistance of the suction apparatus and the physical characteristics of the material to be aspirated also affect the flow rate or removal of fluids from the patient. The resistance of the tubing and suction system limit the flow of liquid and solids, despite increases in the vacuum pressure; however, with these increases in pressure, the flow of air through the system may become excessive and present hazards to the patient. For example, thick, purulent secretions probably will require more vacuum pressure than thin, watery secretions.

Because of their mechanical configuration, most vacuum adapters, suction regulators and collection systems have a built-in resistance to flow. Although manufacturers minimize this resistance to air flow by avoiding use of small-lumen openings, some resistance is unavoidable. Consequently, decreases in flow rate will occur as air or gas moves through the apparatus.

A significant problem with the quick-connect devices used as wall outlets for vacuum is a reduced flow rate due to clogging in the outlet. Clogging results from four major causes:

1. The normal passage of lint-laden room air through the mechanism when regulators remain attached to the outlet and are left on when not in use.
2. The accumulation of aerosols during normal suction procedures.
3. Flooding which follows accidental overflow of aspirated fluids due to shut-off failures or connection errors.
4. Aspiration of smoke and debris during surgical procedures.

All of these risks can be reduced or eliminated by proper use of effective shut-off valves in collection canisters, properly installed over-flow safety traps on vacuum regulators and disposable particulate filters. Filters, however, become more restrictive to air flow as they clean the air that passes through them and accumulate particulate matter. The effective use of filters requires careful monitoring and frequent replacement to maintain optimum flow in hospital vacuum systems. The hospital must create Standard Operating Procedures to change filters and maintain their regulators and gas systems.

A vacuum system flow rate tester is an important tool that can be used to monitor flow rate during normal maintenance procedures and to diagnose low flow rate conditions. This device readily identifies the low flow rates associated with clogged outlets. It can also be used to evaluate equipment and setup options to determine which configurations provide optimal vacuum flow. It is essential to ensure that maximum vacuum flow is available at the wall outlet.

Basic preventive maintenance should include periodic flow measurement at all outlets (with NO vacuum regulator attached). Frequently, poor suctioning performance is attributed to problems with the vacuum system, vacuum regulator or other parts of the patient collection system (when it is the wall outlet system that is contaminated and compromised). Cleaning and repairs should be carried out when outlets are dirty, clogged or have broken quick-connect mechanisms.

When tubing is added to suction apparatus, resistance increases and flow rates will decrease. The single most important factor affecting the resistance of the suction equipment is the length, inner diameter of the tubing, and internal diameter of the catheter and tubing connectors (Figure 5).

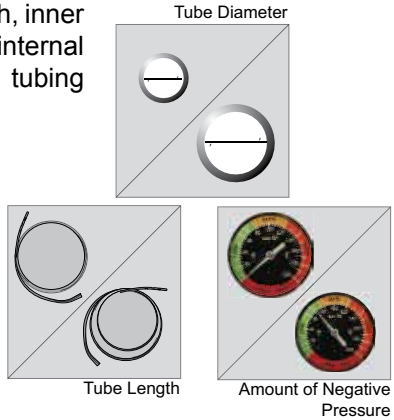


Figure 5

Flow rate can be increased three ways:

1. Increase the inner diameter of tubing and connectors
2. Use shorter tubing
3. Increase negative pressure

In most cases, the increase in flow rate from a larger diameter tube is far greater than the increase in flow

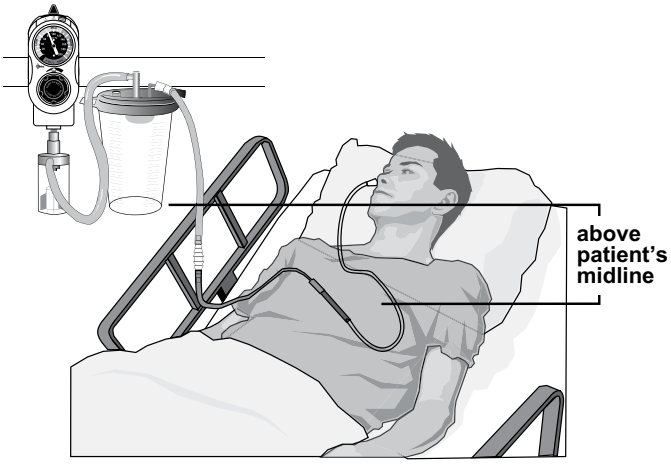
that results from using shorter tubing. A small lumen connector can cause significant flow restriction, even if the tubing's diameter is large. Since the diameters of catheters used in the body for suction procedures is limited by anatomical constraints, only the tubing from the canister to the catheter can be changed. Ideally, that tubing should be as large in diameter (minimum 0.25 in or 6 mm) and as short as possible.

Flow rate is also greatly affected by the viscosity and cohesion of the fluids being aspirated. Sputum, aspirated from the airway, is a highly viscous and cohesive fluid. It resists flow by adhering to the tissue and walls of the catheter and suction tubing. Aspirating sterile water or saline through the catheter before airway suctioning provides a lubricant and helps to improve the flow of mucous. Blood, on the other hand, is less viscous and cohesive and, consequently, flows much more easily through suction systems. Food particles encountered in gastric lavage, nasogastric drainage, or emergency suctioning of aspirated vomitus from the airway may block the catheter, tubing or collection canister inlets.

Even with good flow rate at the vacuum wall outlet, a number of factors can reduce flow rate to marginal levels at the patient. When troubleshooting, make certain that the negative pressure setting is sufficient to raise fluids into the collection canister; that the shortest possible length of tubing is used; that the tubing and connectors are as large as possible and that the vacuum system contains no leaks (see Appendix A). As discussed earlier, flow rate should be regularly monitored at the wall outlet, without a regulator, as part of preventive maintenance.

LOCATION OF COLLECTION CANISTERS

The placement of the collection canister is another important consideration when setting up suction equipment. In nasogastric suctioning, the collection canister is frequently placed higher than the patient, at the point of connection to the suction regulator at the wall vacuum outlet. During intermittent gastric suctioning, the canister is intentionally placed above the patient to avoid the siphon that can develop if the canister were placed lower. This placement also provides a mild gastric reflux to aid in maintaining nasogastric tube patency, a topic that is discussed in more detail later. For continuous gastric suction without vacuum the siphon effect is acceptable; the canister can be placed below the patient's midline so that gravity can enhance fluid removal. If intermittent suction is required, the collection canister must be above the patient's midline (Figure 6).



Collection canister height influences the amount of suction required *Figure 6*

For pleural drainage, the collection canister, used with an underwater seal, must be placed below the patient's chest to avoid the possibility of fluids being drawn back into the patient's chest. This is usually facilitated with use of a chest drainage set system. During surgical procedures, the collection canister is usually placed on the floor.

SUCTION EQUIPMENT

Vacuum Pumps

Vacuum can be produced in a number of ways:

- Through pumps
- Venturi devices
- Gravity

In modern hospitals, vacuum is available for clinical uses through a wall vacuum outlet (pipeline) which is an extension of a centrally located vacuum pump. This pump must be capable of providing high flows, and constant, uninterrupted negative pressure.

Portable pumps can also be used to produce vacuum, particularly for hospital areas not served by the wall system. Negative pressure generated by this equipment may be comparable to wall vacuum when the portable pump is new or well maintained. However, flow rates on some pumps may be lower (assuming equal service life and maintenance) than central systems. Users should identify pressures and flow specifications when evaluating portable units. Consequently, portable suctioning units may be less efficient. Individual pump maintenance on several portable pumps is far more costly and time consuming than maintenance of a central vacuum system.

Another vacuum source is **venturi suction.** Vacuum is produced in a venturi system when pressurized gas (compressed air or oxygen) moves through a small orifice. The high flow rate of the air through the restriction creates negative pressure distal to the orifice; (Bernoulli principle-venturi effect); this negative pressure produced can be captured and used for suction. No separate piped vacuum or electrical connection is required, since piped (or cylinder) oxygen or compressed air provides the driving force. This method is ordinarily used only in emergency, disaster, mass casualty or transport settings when other suction devices are unavailable. Dependence on a gas supply which may be limited (E cylinder), noise created by the venturi, and typically weak flow rates are all limitations of venturi suction.

Pipeline vacuum systems are probably optimal in nearly all hospital environments. Pipeline vacuum saves floor space, is quiet, safe, readily available and is convenient for the hospital staff.

Vacuum Regulators

The amount of negative pressure supplied by a central pipeline vacuum system is greater than that required for most clinical suction applications. A regulator, attached to the wall outlet of the vacuum system, enables the clinician to control the level of negative pressure.

The vacuum regulator limits the maximum amount of suction that can be applied to the patient. It provides constant negative pressure controlled automatically by a mechanical bellows in the regulating module, which allows the regulator to deliver enough flow to maintain the desired negative pressure. This regulating mechanism, which differentiates a vacuum regulator from a needle valve or stopcock controller, responds to fluctuations in either supply vacuum or suction demand at the catheter tip by automatically increasing or decreasing vacuum to maintain the preselected level.

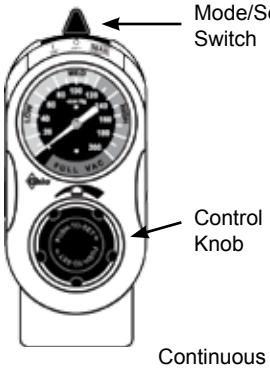
Hospital vacuum regulators always incorporate negative pressure gauges. These gauges are usually calibrated from 0-200 mmHg, and have a full vacuum range to indicate all vacuum levels greater than 200 mmHg up to the maximum available wall vacuum pressure. Some negative pressure gauges are also calibrated in centimeters of water. Gauges used outside the US and Canada use counterclockwise rotation of the gauge needle to differentiate negative pressure from positive pressure, which is always clockwise. Digital gauges, which are more accurate and reliable than analog gauges, are available.

Before adjusting a regulator to select the negative pressure level, clinicians should occlude at the regulator and or at the patient connection, either by placing the thumb over the outlet from the regulator or by crimping or occluding the suction tubing so that it is closed (Figure 7). When the regulator or patient port is occluded in this way, the gauge indicates the maximum pressure that will be delivered at that setting. If the patient port is not completely occluded, the system will be open to the atmosphere and the gauge will indicate a pressure less than the maximum possible negative pressure setting and may result in inadvertent over-suctioning.

Negative Pressure Should be pre-selected
Figure 7

Continuous Vacuum Regulators

The Ohio Medical Continuous Vacuum Regulator is a lightweight, compact unit. It provides simple, trouble-free operation and ease of maintenance (Figure 8). The mode control switch selects the regulator's action. Mode positions are "**REG**ulated," "**OFF**" and "**FULL** Vacuum." In the "Full Vacuum" mode, the internal regulation device is bypassed so that the clinician gets full wall vacuum, possibly up to 635 mmHg. This vacuum may be desirable in the case of emergencies, such as massive hemorrhage by a patient in the operating room or necessity to suction large amounts of secretions from the oral cavity in a resuscitation effort. The three position selector switch is available in two models. One features the standard gauge with color-coded categories (low, medium and high), 20 mmHg numerical increments, and major increment marks every 5 mmHg increase, from zero to 200 mmHg. Another color-coded range is shown on this gauge without increments for all vacuum above 200 mmHg, with the designation "Full Vacuum". The second model features a special high-range gauge which provides increments from zero to 760 mmHg with:



Continuous Vacuum Regulator
Figure 8

- Numerical increments at 100 mmHg intervals
- Major increments each 50 mmHg
- Minor increments each 25 mmHg

A two-position selector switch is also available. This switch has only Off and Regulated modes, thus eliminating the Full Vacuum option for those who do not desire it, two versions are offered:

1. Provides a full vacuum option by turning the regulator control knob to the full-open position.
2. Provides both mechanical stops and a safety relief valve so that negative pressure is limited to a maximum of mmHg, depending on the model.

The vacuum control knob located just below the gauge can be turned to set the desired level of vacuum. Clinicians should select the regulated mode, fully occlude the patient connection, then turn the control knob until the desired degree of negative pressure is indicated on the gauge. The standard gauge on Ohio Medical's Continuous Vacuum regulator indicates millimeters of mercury as well as low, medium and high vacuum. The unit is capable of flow rates up to 110 liters per minute (lpm), depending on equipment configuration, supply vacuum, and flow*.

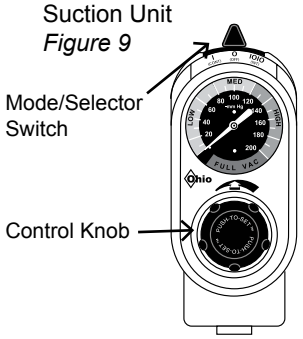
*Remember however that the simple act of attaching a 12 French catheter to a suction system, even if the regulator is set for a maximum value, will reduce total flow through the system.

Intermittent Vacuum Regulators

Some vacuum regulators are designed to meet specialized medical suctioning needs, such as gastrointestinal suctioning. This type of regulator automatically provides interrupted or intermittent vacuum at flow rates that are lower than those generated by constant regulators.

Ohio Medical makes a dual purpose regulator, an Intermittent Suction Unit (ISU) designed to function as either a continuous vacuum regulator or as an intermittent gastrointestinal vacuum regulator (Figure 9). The concept of intermittent gastrointestinal suctioning and Ohio Medical's Intermittent Suction Unit will be discussed in the section on gastric drainage.

Intermittent Suction Unit
Figure 9



Note: Other manufacturers' vacuum regulators may operate differently.

Operating Room Regulators

Operating room suction procedures place special demands on the vacuum delivery system. Operating rooms are usually placed as close as possible to the main hospital vacuum source to ensure availability of higher negative pressures and flows required to quickly move large volumes of fluid. Some suppliers provide vacuum regulators with special design features to meet these operating room demands. These features include the elimination of vacuum limiting devices and addition of selector switches to bypass regulating mechanisms.

Ohio Medical's Surgical/Free-Flow vacuum regulator is designed to operating room specifications. It differs from other units in important ways.

1. A unique clamp-type regulating mechanism allows use of a large-bore, straight through, and open flow path for the maximum flow rates essential for powerful suction. This regulating mechanism will not accumulate lint and aerosols, both of which tend to clog normal regulators and reduce efficiency.
2. The regulating bellows is oversized to respond to the wide changes in vacuum and flow demands that occur when a suction wand is immersed in a pool of blood and/or irrigation fluid in the operative field. It also provides for very rapid adjustment in vacuum levels, requiring only a single turn of the control knob between OFF and full vacuum.

A convenient top-mounted ON/OFF switch promotes conservation of hospital vacuum and allows retention of prior vacuum settings. Two gauge options are available:

1. Standard gauge with 0-200 mmHg increments and a FULL VAC zone, for greater accuracy in the lower negative pressure range.
2. High vacuum gauge with increments throughout the 0-760 mmHg range so that all negative pressures can be measured.

Collection Canisters

When setting up suction equipment, a regulator is attached to a vacuum wall outlet and to a collection canister and tubing. Most regulators are connected directly to wall vacuum by inserting an adapter on the regulator into a vacuum "quick connect" wall outlet. These quick connect outlets open automatically when the adapter is inserted, and close automatically when it is removed. They also secure the regulator to the wall.

Collection canisters accumulate aspirated fluids for accurate clinical measurement and store these aspirated fluids until disposal is convenient. Caps on the collection canisters also prevent aspirated fluids from passing into the vacuum regulator, wall outlet and hospital pipeline system. The caps have either a float that is pushed up by the aspirated fluid as the canister fills, mechanically shutting off vacuum, or a hydrophobic shut-off filter that stops vacuum flow when fluid reaches it. Either the cap or the filter closes off the opening from the canister to the vacuum supply. (Figure 10).

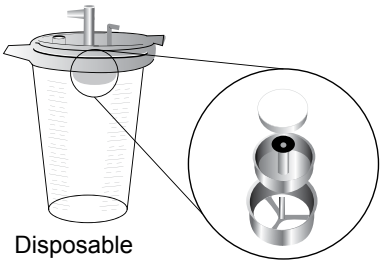
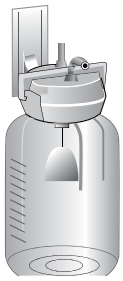


Figure 10

There are several brands of disposable collection canisters used by nearly all hospitals in the US (Figure 11A shows one option). Use of these canisters eliminates the maintenance and cleaning necessary to keep reusable units functioning properly and prevents cross contamination from patient to patient. Both plastic canister and self-contained liner systems are available in sizes convenient for different clinical needs. All feature disposable shutoff valves and many have disposable filter options.

Regulator Trap and Canister
Figure 11A


Reusable Bottle
Figure 11B

Ohio Medical's reusable collection bottles feature a mounting bracket and cap designed to support the trap bottle from the neck (Figure 11B). An integral locking wing secures the cap and bottle to the bracket with a one-quarter turn. The cap contains a positive sealing overflow shut-off valve and float assembly to close off the vacuum supply when the collection bottle becomes full. In addition, a disposable filter traps aerosols, lint and dust. The collection bottles have fluid level markings calibrated in cubic centimeters and are fully autoclavable.

Fluids, aerosols, lint and dust can get into the vacuum regulator and wall outlet, and cause the equipment to malfunction. If these materials get into the pipeline system, they both clog and contaminate it. An overflow safety trap should be connected in the suction line between the collection canister and the vacuum source or regulator. The overflow safety trap* protects the equipment in case of failure of the shut-off valve in the collection canister. Failure of these valves is usually due to improper cleaning or accidental tipping over of the canisters. Filter shut off valves function even when tip-over occurs. The overflow safety trap also collects condensation and droplets, thus preventing excess moisture from entering the vacuum regulator and pipeline system (Figure 12).

Autoclavable Overflow Safety Trap
Figure 12

Ohio Medical's overflow safety traps contain a positive sealing overflow shut-off valve and float assembly to close off the vacuum supply, if the safety trap bottle becomes full. The overflow safety trap is not intended to be used as a collection canister for fluids. It is a safety device to prevent entrance of fluids into the regulator, wall or pipeline system. If grossly contaminated, the overflow safety trap may be cleaned or sterilized by following the manufacturer's guidelines.

*The National Fire Protection Agency (NFPA), which regulates all wall gases and vacuums, states, "Liquid or debris SHALL NOT be introduced into the medical–surgical vacuum or WAGD systems for disposal" (NFPA 99 2012-5.1.14.1.3). In order to do this, Ohio Medical recommends that you use an overflow safety trap and/or filter to protect your regulators and inline vacuum system(s).

Suction Tubing

Suction connection tubing is available in a variety of lengths and diameters; it is either disposable or reusable. Clear tubing is recommended so the aspirated material can be seen. Disposable tubing is most commonly used because it minimizes cross-contamination. The tubing should be of sufficient quality and wall thickness so it will not collapse when exposed to high negative pressures and normal bending. In general, the shortest practical length of tubing should be selected. The inner diameter should be as large as possible to promote adequate suction flow (minimum 0.25 inch or 6 mm). Draping of the tubing across other equipment should be avoided.

Suction Catheters

A wide variety of suction catheters are used in the hospital. Most have special features related to their intended use. Yankauer tip suction wands are typically more rigid and usually have cage-like tips with larger openings. These allow rapid removal of secretions or vomitus from the oropharyngeal cavity in trauma settings or blood and irrigation fluids in the operating room. Catheters for airway suctioning are

smaller and flexible to reduce mucosal trauma and limit obstruction of the airway.

The “whistle tip” catheter has two or three holes, usually perpendicular to each other. This feature reduces the danger of tissue trauma since only one hole may be occluded at one time. The second hole acts as a vacuum relief and prevents the intraluminal negative pressure from building up at the occluded hole, fingertip on-off suction control prevents the application of negative pressure when it is not desired, such as during the insertion of the catheter for airway suctioning. Many suction catheters feature demarcations to identify how deep the catheter is inserted. This is an important feature for endotracheal suctioning as current evidenced based clinical practice guidelines recommended shallow suctioning only (catheter tip no further than the end of the endotracheal tube).

MAINTENANCE OF SUCTION EQUIPMENT

To ensure the continued performance of suction equipment, routine maintenance and inspection are important. Good suction depends on clean equipment. Even the best vacuum pump will be useless with clogged vacuum accessories. Furthermore, every hospital should have a preventive maintenance program, minimize costly breakdowns and keep equipment operating at peak efficiency. Here is a suggested checklist for care of suction equipment after each patient use:

1. Thorough cleaning of reusable equipment and disposal of single-use components
2. Careful inspection of the equipment, with special attention to filters
3. Analysis of performance
4. Adjustment and repair if necessary
5. Re-cleaning
6. Sterilization, if appropriate

Vacuum regulators are downstream from the patient and need to be protected by filtered collection canisters and overflow safety traps, therefore they do not need to be routinely sterilized. If collection canisters are malfunctioning or bypassed and gross contamination of the regulator is caused, the regulator may be sterilized according to manufacturer’s guidelines. Sterilizing without initial routine cleaning can harden collected debris and in turn can result in reduced equipment performance. All tubing should be in good condition and fit tightly to all connections. Overflow valves should be checked to ensure that they are working properly. Filters should be clean and in good condition in order to do their job and maintain high vacuum output.

Manufacturers generally supply operation and repair instruction manuals with their equipment. These manuals should be retained and referred to for both maintenance and repair.

Equipment should be kept in use or used on a rotating basis for the following reasons:

- Unused equipment tends to deteriorate
- Rubber and plastic parts may become stiff or brittle
- Valves may stick

If equipment has been sitting on the shelf or in a crash cart without use, it should be periodically tested to make sure that it will still function properly. Vacuum outlets should be accessible in biomed and central supply, and wherever equipment is maintained. Each piece of equipment should be tested before being released for patient use.

Maintaining the vacuum piping system is as important as maintenance of the suction equipment. The flow rate at the wall outlet should be checked on a yearly basis and suitable cleaning of the outlets should be performed. Acceptable flow rates for vacuum outlets have been published by the Compressed Gas Association and NFPA. Using collection canisters with effective shut-off valves, filters and overflow safety traps will protect the piping system.

SUMMARY

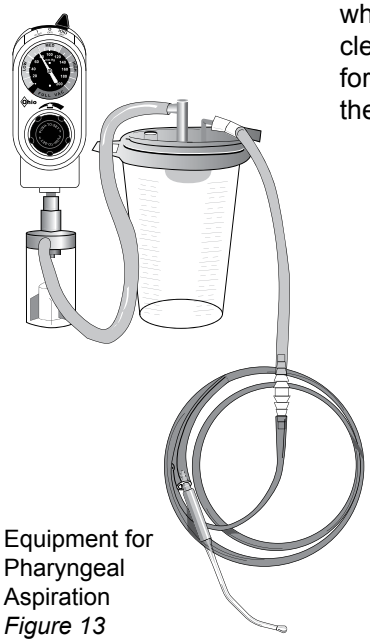
Suctioning is an important part of daily patient care and in many cases can be a potentially life-saving procedure. A thorough understanding of the physics involved in creating suction, the factors affecting flow rate, and the clinical applications of negative pressure will make the procedure more effective and as safe as possible.

USING VACUUM FOR PATIENT PROCEDURES

PHARYNGEAL ASPIRATION

Suction is frequently used to remove excessive secretions or vomitus from the pharyngeal cavities when the patient is unable to clear the airway. Equipment used for pharyngeal suction includes the following items (Figure 13):

- A vacuum source
- Suction regulator
- Collection canister with shut-off float
- Overflow safety trap
- Connecting tubing
- A tonsil tip suction unit, commonly called a Yankauer.

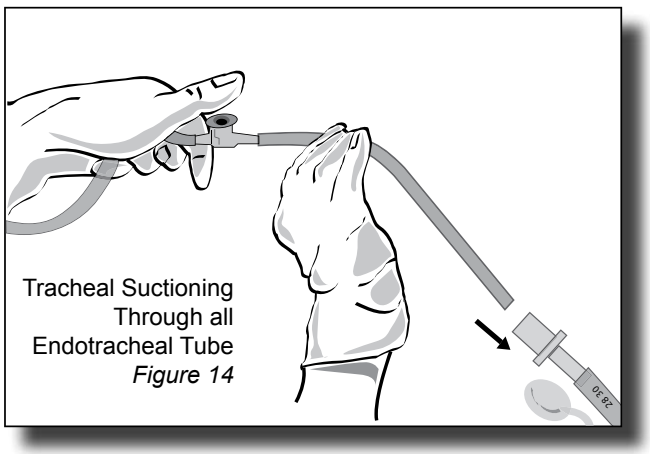


Equipment for Pharyngeal Aspiration
Figure 13

Tonsil suction tips can be either reusable or disposable, but they should be designated for single-patient use to prevent cross contamination. If reusable, the suction tips must be sterilized after each patient's use. Although aspiration of the pharyngeal area should be performed as often as clinically indicated to maintain a patient airway, unnecessary suctioning should be avoided. It can cause trauma to the mucous membranes and lead to edema of the soft tissues.

TRACHEAL SUCTIONING

Tracheal suctioning is used to clear the lower airway of excess secretions to maintain a patient airway. Tracheal suctioning is done either directly or through an endotracheal tube or tracheostomy cannula (Figure 14).



Tracheal Suctioning Through all Endotracheal Tube
Figure 14

Equipment used for tracheal suction includes the following items:

- Vacuum source
- Suction regulator
- Collection canister with shut-off float
- Overflow safety trap
- Connecting tubing
- Sterile disposable catheter.

Multiple-use suction catheters are also available for ventilator-dependent patients. These catheters are housed in plastic sheaths, connected to the ventilator tubing (closed suction systems). To suction, the catheter is pushed out of the sheath and into the artificial airway.

Multiple-use catheters have the following advantages.

- The patient is not disconnected from the ventilator tubing.
- The clinician never comes in contact with the catheter itself.

The catheter unit is usually replaced every 24-72 hours or per hospital policy. Some authors have recommended weekly changes of multiple-use suction catheters. (Respir Care 2003;48(5):494-499) With either type of catheter, the clinician must use appropriate universal precautions.

Negative pressure in the tracheobronchial tree can have several adverse effects on the lungs. Suctioning removes oxygen-rich air, leading to reduced lung volumes and the possibility of atelectasis and transient hypoxemia. If the artificial airway is completely occluded by the suction catheter, the risks are even greater. This danger can be reduced:

- By using the smallest suction catheter to effectively remove secretions
- By limiting the duration of suction to no more than 10 to 15 seconds

The size of the catheter used for tracheal suctioning is very important. As the size of the suction catheter is increased, the negative pressure transmitted to the lungs may also increase. The diameter of the catheter should not be so small as to severely restrict flow but it must be small enough to fit into the endotracheal tube while leaving the airway around it open. A rule of thumb is that the outside diameter of the catheter should be no greater than 50% of the inside diameter of the endotracheal or tracheostomy tube in adults and no greater than 70% of the inside diameter in infants. (see Appendix D). Clinicians can estimate the correct catheter size by multiplying the internal diameter of the airway (in millimeters) by three and dividing by two in adults and by multiplying the internal diameter of the airway (in millimeters) by 3

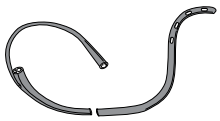
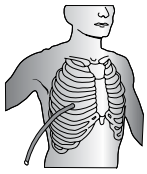
	Dangers	Precautions
Airway Suction	Muscosal damage Hypoxemia Atelectasis	Keep pressure below 80-120 mmHg Make sure outer diameter of catheter is no more than half the inner diameter of airway Give supplemental oxygen and deep breaths
Nasogastric Suction 	Muscosal damage Catheter occlusion	Use double-lumen catheter Use intermittent suction Place collection canister above patient
Pleural Suction 	Recurrent pneumothorax	Make sure the tubing is not occluded

Figure 15

HAZARDS OF SUCTION

and dividing by 1.5 in infants. For example, assuming the goal is to make sure the catheter does not take up more than 50% of the internal diameter of the artificial airway, a number 8 endotracheal tube (8 mm inside diameter) should be suctioned with a 12 French catheter (8 x 3 ÷ 2 = 12). This is based on the fact that outside catheter diameter in millimeters equals the French catheter size divided by three. Therefore, a 12 French suction catheter would have an outside diameter of 4 millimeters which would be exactly one-half the internal diameter of a number 8 endotracheal tube.

Before being suctioned, the patient should be given extra oxygen. Research shows the most effective way to provide extra oxygen is to use a mechanical ventilator (most new ventilators have an automated control for this purpose). If the patient is not ventilator-dependent, a manual resuscitation bag may be used but, it must have a reservoir to maximize the oxygen concentration. Pressures and volumes used should be monitored and limited. **Suction should NEVER be applied during catheter insertion, between passes of the catheter, and the end of the procedure, unless high frequency ventilation is being used.** Patients' oxygenation and cardiac rhythm should be monitored during the procedure and suctioning should be stopped immediately if there is a precipitous drop in oxygen saturation, as monitored by pulse oximetry, or a change in cardiac rhythm. The durations of the

entire procedure should not be more than 15 seconds (AARC CPG 2010).

The amount of negative pressure needed for tracheal suctioning is dependent on a number of factors, including the diameter of the catheter and the physical properties of the secretions being removed. The least amount of vacuum necessary to draw secretions into the collection canister should be used. The literature[2] suggests a range of between 80-120 mmHg negative pressure for adults (with a maximum of 150 mmHg). The suggested range of negative pressure for neonates is between 80-100 mmHg in an Expert Panel referenced based Clinical Practice Guideline[2] (AARC 2010).

Evidenced based clinical practice guidelines recommend that only shallow suctioning[2] be performed. The catheter should not be advanced past the end of the artificial airway. Shallow suctioning can be accomplished by aligning the markings on the endotracheal tube with the markings on the suction catheter.

For example, in the above picture, the 28 marking on the endotracheal tube is aligned with the 28 marking on the suction catheter.

Subglottic Secretion Removal (SSR), also known as Continuous Aspiration of Subglottic Secretions (CASS)

Endotracheal tube (ETT) intubation impairs cough and mucociliary transport. Dormant mucus can lead to atelectasis, airway infection, and respiratory compromise. ETT's prevent the normal physiologic protection against aspiration so that secretions from the oropharynx can collect above the ETT cuff and be aspirated into the lungs, potentially leading to a hospital acquired infection (HAI) labeled ventilator-associated event (VAE). Data shows ventilator-associated events (VAE) are not uncommon in patients on mechanical ventilation (MV). Depending on the surveillance methodology applied for the identification of VAE, the risk of this complication ranges from 1.2 to 8.5 cases per 1,000 ventilator days (0.6%-4%). VAE is associated with increased hospital length of stay, mortality, infections due to multi drug-resistant pathogens, and an increased hospital cost of approximately $10,000 to $25,000 per patient.[3,5]

Multiple interventions are used in efforts to prevent VAE and there is a rising interest in interventions associated with the endotracheal tube (ETT) being identified as one of the main items associated to VAE.[2,3] An ETT tube is considered one of the major risk factors for VAE, acting both as a reservoir for likely infecting microorganisms and as a channel between the oropharyngeal space and the sterile bronchoalveolar space by bypassing the host defenses.[5,6] The most important mechanisms associated with the development of VAE are microaspiration and biofilm formation. Microaspiration occurs when microorganisms within secretions collecting above the ETT cuff get around the cuff and migrate into the lower airway. Six Common efforts to prevent or reduce VAE include:

1. Semi Fowlers Positioning (30-45 degrees)
2. Oral Care
3. Subglottic Secretion Removal (SSR)
   - Continuous Aspiration Subglottic Secretions (CASS)
   - Intermittent suctioning
4. Cuff Pressure Regulation (20-30 cmH_2O)
5. Safe suctioning
6. Biofilm reduction/ removal

The Centers for Disease Control* recommends "If feasible, use an endotracheal tube with a dorsal lumen above the endotracheal cuff to allow drainage (by continuous or frequent intermittent suctioning) of tracheal secretions that accumulate in the patient's subglottic area." Specialty designed ETT's for Subglottic Secretion Removal (SSR) can aspirate secretions accumulating above the ETT cuff through a third lumen located dorsally (above the ETT cuff) which permits intermittent or continuous aspiration of subglottic secretions (Figure 15A). Accumulations of these secretions above the ETT cuff contribute to costly HAI's.[1,2] SSR or Continuous Aspiration of Subglottic Secretion (CASS) tubes have been available and in use for several years. Although these SSR tubes are recommended and evidence supports that these tubes reduce VAE rates by almost 50%[7-9], widespread use of SSR tubes has not been adopted due to cost, reported complications and undesirable effects associated with SSR use. These complications include tracheal mucosal damage, tracheal-esophageal fistula and obstructed lumen with tissue mucosa.[10-12]. When the dorsal SSR tube lumen becomes occluded, the tube can not serve

*CDC GUIDELINE (II) (44, 134-137)

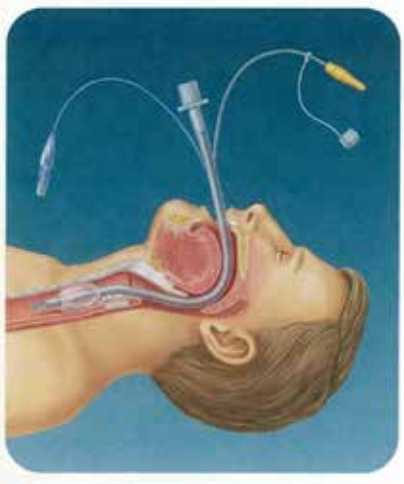
its purpose in removing subglottic secretions and is rendered ineffective. The design of these specialty SSR tubes has been questioned as contributory to these complications and manufacturers have acted to improve their designs. Lack of knowledge about SSR and CASS and human behavioral elements relative to the proper technique to set appropriate vacuum pressures result in excessively high pressures and inadvertent oversuctioning, which may also contribute to complications and tracheal mucosal injury.

It is imperative that the correct vacuum pressures are used for SSR and that the recommended technique is followed when setting vacuum regulator pressure otherwise inadvertent oversuctioning will occur. Generally, 20-30 mmHg of vacuum is recommended for continuous aspiration of subglottic secretions and 80-120 mmHg for intermittent subglottic secretion removal.

Specialty CASS regulators which limit pressures and are presently continuous vacuum only are available. If intermittent vacuum, as recommended, is desired, an intermittent vacuum regulator should be used.

If it is suspected that the dorsal lumen (SSR) is occluded, the port should be purged with air using a syringe (according to all manufacturers of the specialty tubes instructions for use). Higher vacuum pressures should NEVER be applied to the port as mucosal injury may occur.

Figure 15A



Cuff Pressure Regulation

Underinflation of the tracheal cuff frequently occurs in critically ill patients and represents a risk factor for microaspiration of contaminated oropharyngeal secretions and gastric contents that plays a major role in the pathogenesis of ventilator-associated pneumonia (VAE).[6] In spite of manual control of cuff pressure (Pcuff) using a manometer, underinflation (< 20 cm H_2O) and overinflation (> 30 cm H_2O) of the tracheal cuff frequently occurs in intensive care unit (ICU) patients [(7,8)]. Underinflation and overinflation of the tracheal cuff are well-known risk factors for VAE and tracheal ischemic lesions[(9,10)], which are associated with important morbidity and mortality in ICU patients[(11,12)].

Recently, devices allowing efficient continuous regulation of Pcuff have been developed[(8,12)]. In vitro[(12)], animal[(13)] and human[(7,12)] studies have demonstrated that these devices are more efficient in controlling Pcuff than routine care using a manual manometer and or syringe.

Biofilm

The endotracheal (ET) tube has long been recognized as a major factor in the development of VAE since biofilm harbored within the ET tube can become dislodged during mechanical ventilation and have direct access to the lungs. This biofilm build up also decreases the inner diameter of the ET tube causing increased resistance and increased work of breathing.[(4)]

Mechanical removal of biofilm has been suggested with the use of devices that mechanically remove the biofilm (e.g. CAM Rescue Cath™ and Mucus Shaver, modeled similar to the Rescue Cath). These devices have inflatable Teflon or silicone rubber cuffs integrated into a suction catheter that is introduced into the ETT for extraction of material accumulated inside. Once the device is inserted to the end of the ETT, the cuff is inflated and the catheter slowly removed to mechanically strip the inside of the ETT. The safety and efficacy in the devices have been shown in animal models, case studies, and in randomized trials.

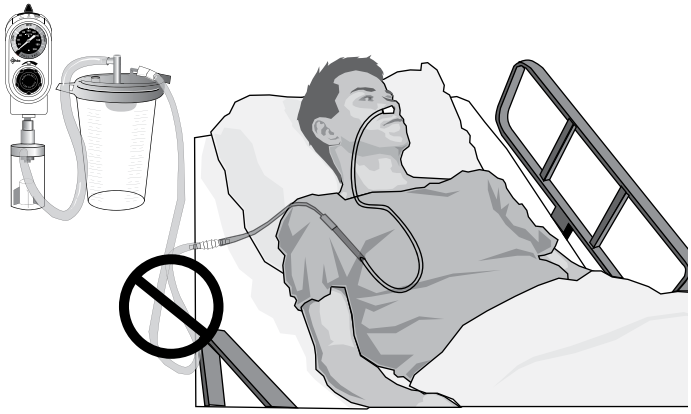
GASTROINTESTINAL SUCTION

Gastrointestinal suction removes materials and gases from the stomach and intestinal tract. In most cases, gastric drainage is used to prevent gastric juices from accumulating in the stomach when the bowels are not functional, for example, post-operatively or after major trauma.[1]

Recommended equipment includes the following:

- An intermittent suction unit connected to wall vacuum
- An overflow safety trap and/or filter
- A collection canister (placed higher than the patient)
- Connecting tubing
- A nasogastric tube (NG) or catheter

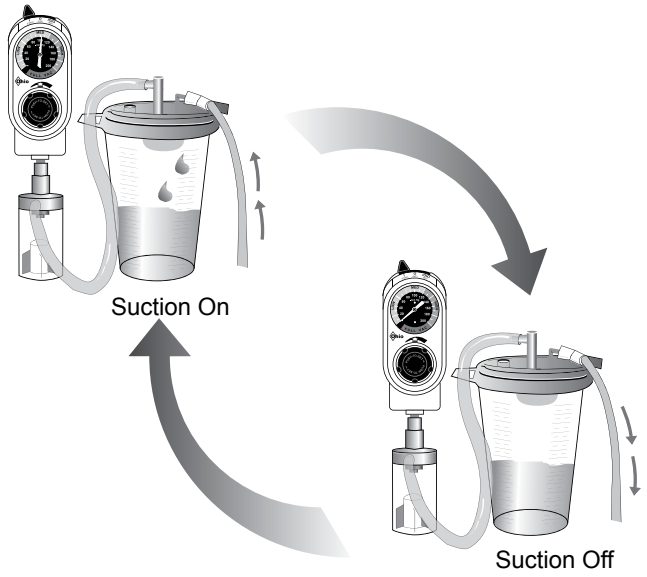
There should be no dependent loops in the connecting tubing between the collection canister and the patient. The tubing should be as short as possible since flow will decrease with longer tubing (Figure 16).



Avoid Dependent Loops
Figure 16

As suction is applied to the stomach and its contents are removed, the stomach tends to collapse around the suction tube. The hole(s) in the distal end of the suction tube may be drawn toward the tissue surface as the stomach collapses, resulting in steady suction on one spot of the stomach lining. Not only does this block the drainage tube and prevent secreted fluids from leaving the stomach, it also can wear away the mucosal lining and cause ulcerations, hemorrhage or perforation at that spot.

Intermittent suction can minimize these problems. During each full intermittent suction cycle, the catheter tip moves away from the stomach wall as negative pressure is reduced to atmospheric pressure for a predetermined (in some cases, adjustable) period of time, usually 8-10 seconds (Figure 17).



Automatic Cycling of Suction
Figure 17

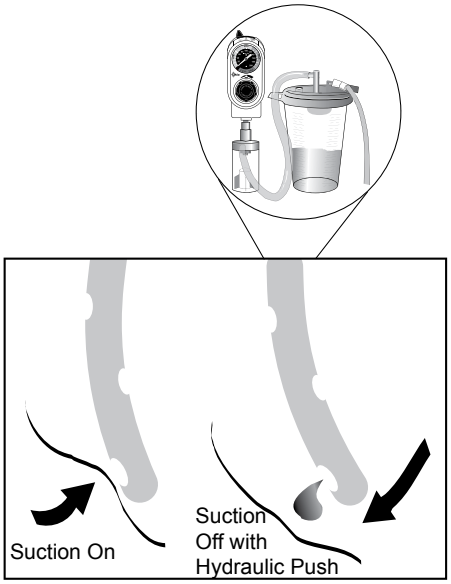
In addition, intermittent suction can provide a noticeably more efficient means of draining the cavity of mixed material than continuous suction, due to this automatic cycling of negative and atmospheric pressure. Ideally, gastrointestinal suction regulators should provide moderate intermittent vacuum with low flow rates.

One type of gastrointestinal suction device is the portable thermotic pump. This electrically powered unit operates on Charles' law which states that when the temperature is changed, a given volume of air will expand (with heat) or contract (with cold). A volume of air in an enclosed space of the thermotic pump is heated, the air expands and some of it escapes through a one-way valve. The heating cycle then stops, allowing the air in the closed space to cool and contract, lowering the pressure and creating a vacuum. A thermotic pump provides interrupted suction by the "on" and "off" of the heating cycle, but the pressure in the apparatus does not return to atmospheric pressure or gauge zero during the "off" cycle. This type of unit cannot be adjusted for various negative pressures, but is limited to a low pressure of approximately 90 mmHg and a high pressure of approximately 120 mmHg.

A specialized gastrointestinal suction regulator used with a central pipeline vacuum system provides a simple, compact apparatus for gastric suction. This type of set-up generally has few connections and offers the highly desirable feature of intermittent suction. For maximum clinical benefit the regulator must supply "true" intermittent suction as well as the option of a continuous suction mode of operation.

Ohio Medical's Intermittent Suction Unit (ISU)

The ISU provides true intermittent suction. When the unit is in the "off" phase of the intermittent cycle, suction stops and the system returns to atmospheric (gauge zero) pressure. When the unit cycles off, any liquids in the tubing will flow back into the stomach via gravity, creating a hydraulic "push" (Figure 18). This



Intermittent
Suction Cycle
Figure 18

action will tend to move the catheter away from the stomach wall and clear the catheter tip of any solids which may be clogging it. Consequently, the need for irrigation of the gastric tube to maintain patency will be reduced.

To assure this hydraulic "push" will occur, the collection canister must be located above the level of the patient and the drainage tubing must not be draped to allow gravity to pull fluid back into the stomach. If the collection canister is placed below the patient, a siphon action will develop resulting in continuous rather than intermittent suction. When the collection canister is located above the patient, a greater amount of vacuum is required to lift the liquid up the tube. (See Location of Collection Canister page 6.)

Ohio Medical's Intermittent Suction Unit is a dual-purpose instrument; it provides either intermittent or continuous suction depending on clinical needs. The continuous mode operates in the same way as Ohio Medical's Continuous Vacuum Regulator. It provides continuous, uninterrupted suction at a pre-set negative pressure selected by the clinician. This mode can be used before starting intermittent gastric drainage to set the level of negative pressure more easily and to rapidly decompress the stomach. The continuous mode is suited for removal of accumulated volumes of fluid or gas. In contrast, the intermittent mode is designed for long-term use for handling normal secretion volumes. The dual-mode capability also provides complete versatility of use:

- True intermittent gastric drainage (which returns to atmospheric, gauge zero pressure when off)
- Continuous gastric drainage
- Continuous airway
- Surgical suctioning

To provide intermittent suction, the unit uses a quiet and reliable pneumatic logic device to alternately turn the vacuum "on" and " off. " The unit can be adjusted to provide from zero to 200 mmHg negative pressure as well as full line vacuum.

The timing of the "on" and "off" cycles is important to the successful operation of intermittent suction. The "on" cycle should be approximately twice as long as the "off" cycle. The length of time for removing the fluid should be longer in order to allow for adequate drainage into the collection canister before the start of the "off" cycle. The vacuum should be "off" long enough to allow the system to return to atmospheric (gauge zero) pressure and allow the hydraulic "push" to flush the tube (e.g. the cycles on Ohio Medical's ISU are preset at the factory to provide approximately 15 seconds "on" and 8 seconds "off").

When used in the intermittent mode, Ohio Medical's ISU has been set to create vacuum flows of 8 lpm at any regulator pressure, from 80 mmHg to full line vacuum. The unit will provide up to 80 lpm in the continuous mode. There are two reasons for the slower intermittent flow rate:

1. When the unit cycles on, high flows could be extremely uncomfortable for the patient if the patient's stomach decompresses too rapidly.
2. With slower flow rates there is less possibility of catheter occlusion, which, in turn, allows for more complete emptying of the stomach.

Factory flow rates have been set at levels usually appropriate for clinicians. However, if the clinician needs a flow rate different from that set at the factory, trained personnel from the hospital biomedical engineering or maintenance departments can adjust the regulator's flow rate by following the instructions in the service manual.

During intermittent suction, liquid will occasionally travel only partially up the tubing during each "on"

cycle. Reasons for this, with suggested corrective actions include the following:

1. The negative pressure may not be high enough to lift the liquid all the way up the tube and into the collection canister. Increase negative pressure gradually until the fluid moves into the canister. Be certain to occlude* the patient tubing when setting/increasing negative pressure.
2. The stomach may be completely drained of liquid. In this case, leave the system operating as is to remove additional fluid as it accumulates.
3. There may be more solid than liquid in the stomach which is blocking the tube.

Follow standard hospital procedures for irrigating the nasogastric tube to clear the blockage, then resume intermittent suction. If the liquid rises a little close to the collection canister with each "on" cycle, and eventually collects in the collection canister, the system is probably working effectively.

*Ohio Medical's Push-To-Set™ technology offers a unique integrated passive safety system design to prevent inadvertent over-suctioning; when the vacuum adjustment knob is depressed, the vacuum flow path is "automatically occluded" and will accurately reflect maximum suction pressure.

PLEURAL SUCTIONING

The main objective of pleural drainage is to remove air or fluid from the pleural space so that the lung can re-expand to its original dimension. Pneumothorax is the term that is used to describe air in the pleural space. There are two types of pneumothorax:

1. An open pneumothorax occurs when the chest wall and lung have been penetrated, such as during a stab or gunshot wound, or after a surgical incision.
2. A closed pneumothorax occurs when the lung ruptures, but the chest wall remains intact and not perforated such as with blunt trauma.

Different types of fluid can accumulate in the pleural cavity for a variety or reasons. Transudates can occur with congestive heart failure. Exudates can develop following inflammation or malignancy, blood (hemothorax) can collect after chest trauma or surgery, and pus (empyema) can accumulate with infection (Figure 19).

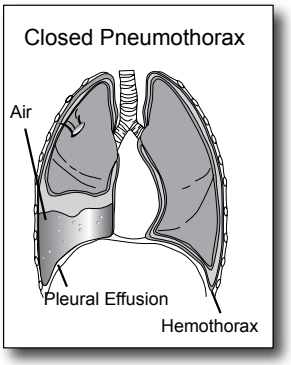
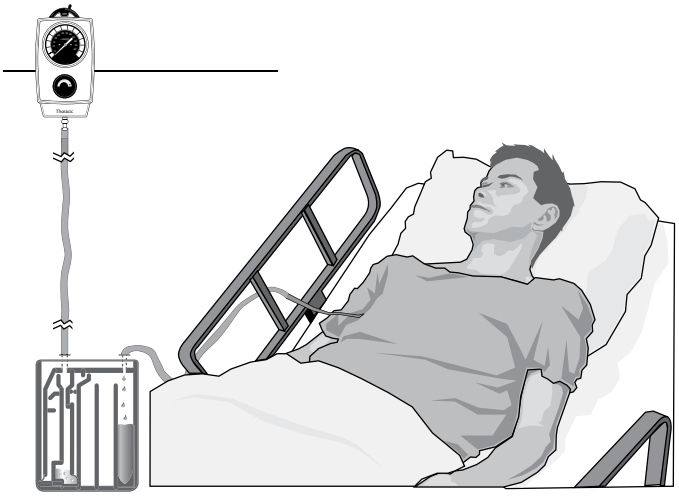


Figure 19

In order to keep the lungs expanded against the chest wall, negative pressure must be maintained in the pleural space. If air or fluid gets into the pleural space, negative pressure is reduced and the lungs will collapse. Pleural drainage removes both fluids and air from the pleural space re-establishing the negative pressure which allows the lungs to re-expand.

Equipment used for pleural suction include the following items (Figure 20):

- A vacuum source
- Suction regulator
- Connecting tubing
- A chest drainage system connected to the patient's chest tube



Pleural Suction System
Figure 20

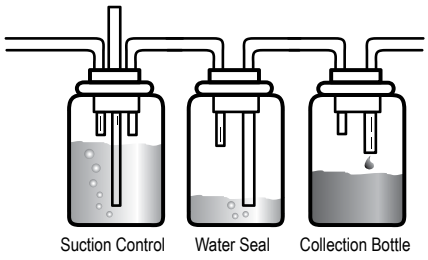
Sometimes, a simple gravity/water seal drainage will be enough to re-expand the lung. Air and/or fluid will leave the pleural cavity but will not enter the chest because the water seal will act as a one-way valve. If there is a significant hole in the lung and a resultant large air leak, the chest drainage system must be connected to suction. Traditionally, in hospitalized patients, all chest drainage units are connected to suction.

An accurate pressure limiting device is necessary to regulate the amount of negative pressure transmitted to the pleural space. The normal range of negative pressure in the intrapleural area is 5 to 20 cm H_2O This is the range that is usually used in chest drainage systems as well.

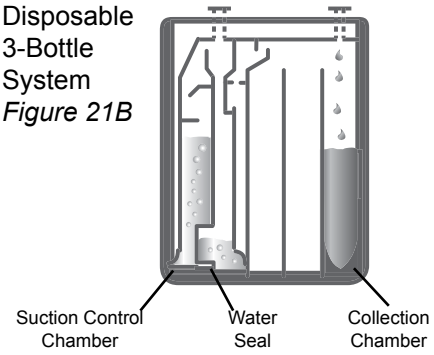
Because very low negative pressures (usually 20 to 40 cm H_2O) are required for thoracic suction, a more accurate pressure limiting device is necessary. Years ago, a three-bottle system was developed for

evacuation of the pleural cavity (Figure 21A).

Reusable 3-Bottle System
Figure 21A



Disposable 3-Bottle System
Figure 21B



Today there are a variety of pleural drainage devices on the market that incorporate the principles of the three-bottle system in disposable, molded plastic units (Figure 21B).

The suction control bottle (or chamber, in the plastic units) provides a water column to regulate vacuum levels. The water seal bottle creates the underwater seal to act as a one-way valve for air to leave the chest and not re-enter the pleural cavity. The collection bottle is a reservoir for fluids drained from the chest. Most of these units are connected to hospital wall vacuum. They have only a few limitations:

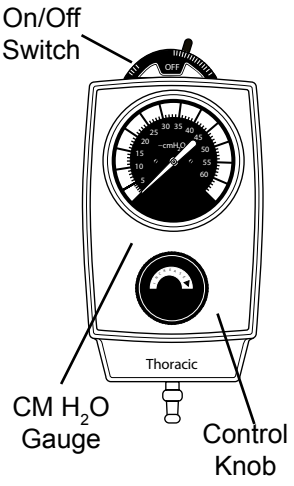
- 0-30 cm H20 vacuum range
- Noise from the vacuum flow bubbling through the water column
- The need to add or remove water from the suction control chamber (or bottle) in order to change the negative pressure transmitted to the pleural space

Newer generation chest drainage systems which provide dry suction instead of wet suction and a one way valve instead of the underwater seal also exist. Dry suction control systems are controlled by a regulator instead of a water column and provide advantages such as easier set up and quieter operation. These systems have a one-way valve which replaces the underwater seal.

When using the chest drainage system, pressure is regulated at the chest drainage system and the vacuum regulator in the wall is used to “power” the system. Chest drainage systems manufacturers recommend a pressure for the wall regulator (usually 80 mmHg) and this recommendation must be followed.

Thoracic Vacuum Regulator

Ohio Medical’s specialty regulator designed for use with pleural and mediastinal drainage systems is the Thoracic Vacuum Regulator (Figure 22). This regulator features a unique, oversized regulating diaphragm for the precision control and adjustments required for chest drainage. The gauge is calibrated in centimeters of water instead of millimeters of mercury, with a low range scale of 0-60 cm H_20 and increments that match the precision of the regulating mechanism. Two other important design features are:



Thoracic Vacuum Regulator
Figure 22

1. A positive pressure relief valve to vent accumulated or transitory pressure buildup
2. A high flow rate capability designed to compensate for air leaks in the thoracic cavity.

The regulator control knob, geared for precision, requires several turns to move the gauge needle over a small range but allows selection of any negative pressure from 5-55 cm H_2O. The regulator can accommodate a second chest tube. In addition, a convenient ON/OFF switch allows retention of prior settings. When the vacuum system is turned off using the ON/OFF switch, the positive pressure relief valve will vent any accumulated positive pressure in the drainage system.

Use of the Thoracic Vacuum Regulator serves the same function as the suction chamber or bottle of the chest drainage system; therefore, no water is needed in that part of the system, and the unit will be silent.

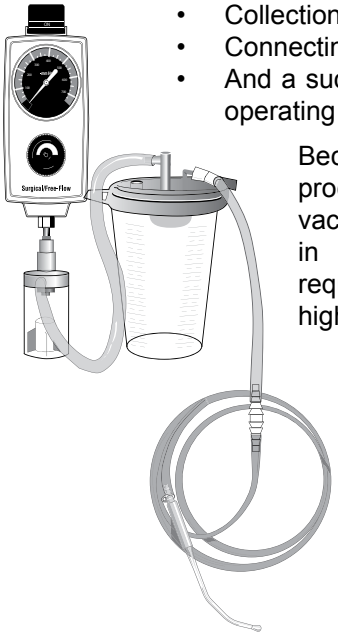
When using the chest drainage system, pressure is regulated at the chest drainage system and the vacuum regulator in the wall is used to “power” the system. Chest drainage systems manufacturers recommend a pressure for the wall regulator (usually 80 mmHg) and this recommendation must be followed.

SURGICAL SUCTIONING

Suction is essential in operating room environments and is used during surgery to keep the operating field clear of blood, secretions, and irrigation fluids. At the same time, airway suctioning may be performed by the anesthesiologist or anesthetist to maintain airway patency. Postoperatively, gastrointestinal and/or chest tubes may be used for drainage.

Equipment used for surgical suction includes the following items (Figure 23):

- A vacuum source
- Suction regulator
- Overflow safety trap
- Collection canister(s) with a shut-off float
- Connecting tubing
- And a suction catheter or tip used in the operating field



Equipment used for Surgical Suctioning
Figure 23

Because of the numerous suction procedures, a sufficient number of vacuum outlets should be available in the operating room. Vacuum requirements range from the high flows and negative pressure needed in cases of massive hemorrhage or vomiting to the fine control needed when working with delicate tissue, such as microsurgery. Most suction procedures should be done with regulated control of the negative pressure. Vacuum regulators with a switch or control knob that allows the operator to immediately obtain full wall line vacuum are preferable for maximum flexibility.

Extreme caution must be used in surgical applications: DO NOT apply the suction trocar tip too close to blood vessels and or vital organs; contact with vital organs or blood vessels may result in serious patient injury.

In order to minimize flow rate reduction, all areas in the hospital, especially the operating room, should use large bore tubing and large inner diameter suction system fittings. Since some operative procedures yield large liquid volume in short periods of time, the suction system must be able to remove accumulated fluid quickly. Small bore catheters are incapable of performing this task.

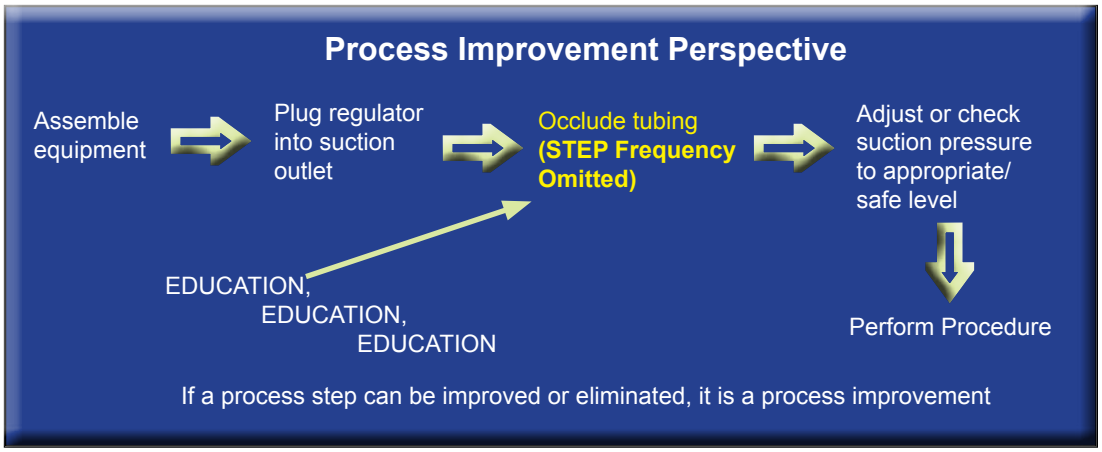
Sump tubes can be used to keep the surgical site clean when fluid production is slow but continuous. Yankauer (or tonsil) suction tips are usually used to clear fluid that obscures the operative site. Pressure regulated suction flow can be diverted through a catheter or suction tip by using a fingertip flow control. Once the regulator is set at a predetermined suction level, the clinician can apply suction by placing the thumb over the flow control opening.

The collection canister for surgical wound drainage should be placed on the floor as close to the patient as possible, in lieu of above patient's midline. This lower placement eliminates the need for additional negative pressure that would be required to lift materials up into the canister. Placement of the collection canister on the floor also reduces the possibility of occluded tubing. As protection against accidental overflow of fluids into the suction regulator and hospital vacuum system, an overflow safety trap and/or filter should be used with the collection canister.

IMPORTANT INFORMATION FOR SETTING A VACUUM REGULATOR APPROPRIATELY:

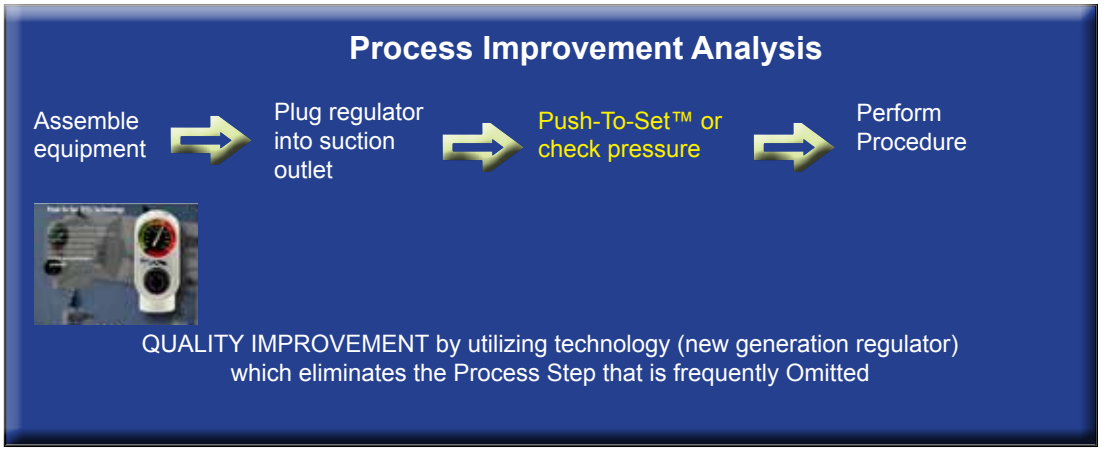
Improperly set vacuum regulators can expose patients to vacuum pressures up to 15 times higher than recommended pressures for suction procedures.[1] Use of higher than recommended pressures can cause suction induced lung derecruitment and tear the delicate mucosal tissue in the stomach or trachea, leading to inflammatory response, bleeding and potential infection.[2] Research indicates that the prevention of suction-induced lung derecruitment is more clinically relevant than reversal of Acute Lung Injury or Acute Respiratory Distress Syndrome (ARDS).[3] Many clinicians, however, do not fully understand how they can help to prevent these complications through the proper use of vacuum regulators. Evidence based clinical practice guidelines and manufacturers' recommendations state that the negative pressure of the unit must be checked by occluding the end of the suction tubing before attaching it to the suction catheter, and prior to each suctioning event. Data shows that this important step (occluding the tubing or occluding at the vacuum regulator to set the regulator) is frequently unknown and/or not performed, resulting in inadvertent oversuctioning. Inadvertent oversuctioning may cause mucosal trauma, inflammatory response, bleeding, infection and, with endotracheal suctioning, traumatic atelectasis.

In process analysis, the "occlude to set or check the vacuum pressure" is the problem step (often omitted).


Process Improvement Perspective
Assemble equipment
Plug regulator into suction outlet
Occlude tubing (STEP Frequency Omitted)
Adjust or check suction pressure to appropriate/ safe level
EDUCATION, EDUCATION, EDUCATION
Perform Procedure
If a process step can be improved or eliminated, it is a process improvement

Failure to occlude to set is a human behavioral element which requires education and training, policy and procedure attention, and competency testing. Despite considerable efforts by clinical leadership, this human behavioral element frequently persists and the maximum vacuum pressure setting is not properly set. This results in inadvertent over suction and possible patient injury.

New vacuum regulator technology has been developed to eliminate the problem step (occluding to set) and is available. From the process improvement perspective, this new technology eliminates the need to occlude the tubing or regulator to set or check the maximum pressure (Ohio Medical's Push-To-Set™ (PTS) vacuum regulators).


Process Improvement Analysis
Assemble equipment
Plug regulator into suction outlet
Push-To-Set™ or check pressure
Perform Procedure
QUALITY IMPROVEMENT by utilizing technology (new generation regulator) which eliminates the Process Step that is frequently Omitted

The Push-To-Set™ vacuum regulators require the clinician to push in the pressure dial to set the maximum pressure. Pushing in the pressure dial occludes the vacuum port so setting or checking maximum pressure is accomplished appropriately. Vacuum pressure (with PTS) can not be changed without pushing in on the dial, thereby negating the human behavioral element for occluding the tubing or regulator.

Clinical Applications

Gastrointestinal Intubation

Gastrointestinal intubation has been in common clinical use for approximately 70 years. The use of a gastric tube was first reported by John Hunter in 1790. Hunter used the tube to feed a patient who could not swallow. In the early 1800s, researchers in Philadelphia and London used gastric tubes to wash out stomachs after poison ingestion. A century later, investigators reported successful treatment of intestinal obstruction (ileus) with gastric tubes. No suction was applied to the tube. Instead, the end of the tube was placed below the patient so that a siphon effect would empty the stomach. In the 1920s and 1930s, Wangensteen and others determined this method of drainage was not adequate and that suction was necessary to empty the stomach. The early Wangensteen suction devices were complicated configurations that generated minimal vacuum of approximately 20 mmHg of continuous negative pressure. These devices were replaced by the electric thermotic suction devices and then vacuum regulators as more and more hospitals installed wall vacuum access. Now, intermittent suction units that provide true atmospheric pressure during the off cycle are the state-of-the-art devices.

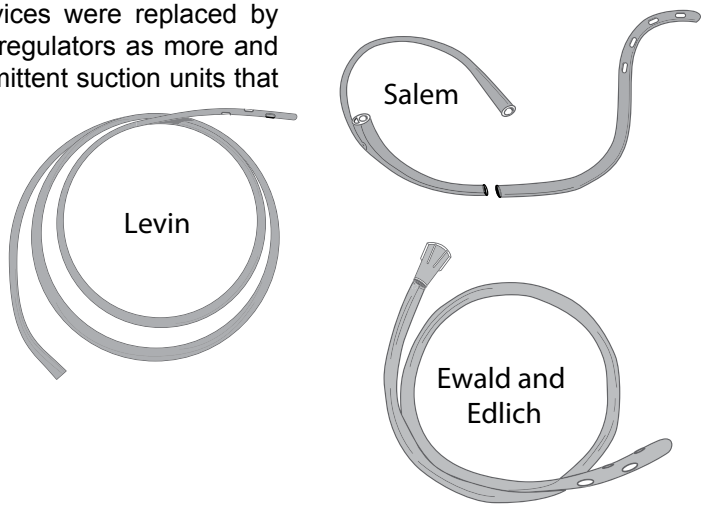


Figure 24

Gastric Tubes

There are three basic types of gastric tubes in common use (Figure 24):

1. Double-lumen Salem sump
2. Single lumen Levin tube
3. Large Ewald and Edlich tubes

Salem Sump Tube

This is a clear plastic, double-lumen tube, used most commonly for long-term nasogastric drainage. The larger (primary) lumen has holes at the tip and along the distal sides of the tube. It is used to drain the stomach. The smaller lumen, the vent port - identified by a blue “pigtail” at the proximal end - is designed to allow air to enter the stomach during suction to modulate the effect of negative pressure to reduce the risk of the tube adhering to the stomach wall. If drainage decreases unexpectedly, the likely cause is primary lumen blockage. Air can be injected into the pigtail (without disconnecting the primary lumen from suction) to move the tube away from the stomach wall or to dislodge particulate matter from the end of the tube and enhance drainage. Only air can be injected into the vent port. The “pigtail” should never be tied off or clamped since tying off or clamping will eliminate its protective function.

If gastric contents regurgitate through the vent port, the vent lumen will be partially or fully blocked. If it bubbles, it is functioning. If blocked, it cannot function. This occurs when gastric pressure is greater than intraluminal pressure. There are several reasons for the reflux. The collection bottle or the port itself may be too low relative to the distal end of the tube in the stomach, so that a siphon has been created. If raising the tube and collection bottle does not solve the problem, the tube may need irrigation. A short period of continuous low-pressure suction may be needed to empty the stomach and reduce the gastric pressure. As a last resort, the level of negative pressure may need to be increased. Suppliers offer optional one-way valves or filters that allow air to enter the secondary lumen and prevent fluid reflux from escaping the tube and soiling the patient.

Levin Tube

The Levin tube is a single lumen, clear plastic tube. At one time, it was the most common tube for gastric drainage. Over the years, the double lumen tube has become the tube of choice for gastric drainage. The Levin tube now is used for short periods to assess gastric contents for the presence of blood or to decompress the stomach after resuscitation. Smaller-lumen tubes may be used for longer periods to provide tube feedings or medication. Because of their risk of adherence to the stomach wall with continuous suction, these single-lumen tubes are not regularly used for standard gastric drainage.

Ewald and Edlich Tubes

The Ewald and Edlich tubes are large single-lumen tubes with multiple openings at the distal end. They are used for gastric lavage to remove ingested poison (particularly following overdose) or large blood clots resulting from gastric bleeding. Because of its large diameter, the tube allows rapid, high volume evacuation of gastric contents. The tube is inserted through the mouth into the esophagus and then into the stomach. It is only used long enough to remove specific gastric materials and/or to lavage the stomach.

Insertion of Nasogastric Tubes

Ohio Medical publishes a separate booklet, A Step by Step Guide for Nasogastric Tube Insertion. This photo guide illustrates the equipment needed for insertion of Salem sump and Levin tubes and the placement procedure. For a copy of the publication, either contact your Ohio Medical representative, or call Ohio Medical Corporation (866-549-6446 or 847-855-0500).

Care of Nasogastric Tubes

Nearly all nasogastric tubes are uncomfortable to patients. Placement of the tube through the nose requires breathing in and out of the mouth, which leads to mucosal drying. However, ongoing attention to oral hygiene can reduce the level of discomfort and protect delicate tissues. Depending on the patient's condition, this mouth care may consist of brushing the teeth, using mouthwash for oral rinsing, or swabbing the teeth and mucosa. Frequent lubrication of the lips and nostrils with a water-soluble lubricant will also make the patient more comfortable. Products containing alcohol exacerbate drying and should be avoided. If not contraindicated, the patient can chew on ice chips to keep the mucosa moist.

Periodic tube irrigation with fluid may be ordered by the physician or recommended by hospital policy and procedure. Fluid cannot safely be instilled into the tube until correct placement of the tube has been confirmed. Placement in the stomach can be confirmed by two procedures: the identification of gastric contents being removed through the tube and by instilling air into the tube with a syringe and listening for a gurgle over the epigastrium. The amount of irrigation fluid instilled and the amount removed should be noted for intake and output record-keeping.

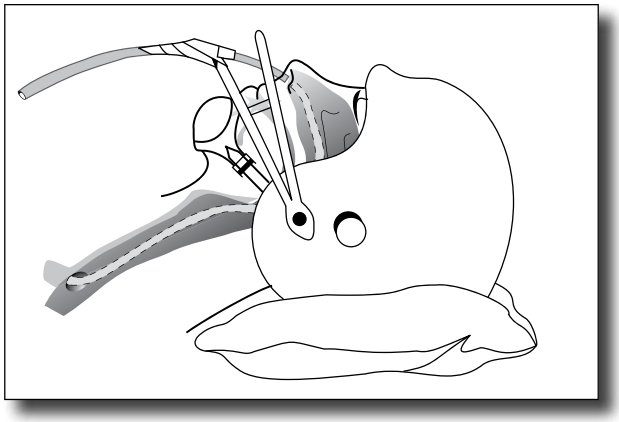
Patient monitoring should include assessment of the color, consistency and amount of drainage from the gastric tube. Presence of bowel sounds in the abdomen should be noted. When bowel sounds return, indicating peristalsis, the tube can usually be removed since gastric secretions will no longer collect in the stomach. Monitoring stomach contents to determine gastric pH for patients with nasogastric tubes in place helps clinicians determine whether patients at risk for stress ulcers need pharmaceutical therapy or if prescribed therapy is working.

Gastric pH can be measured two ways. One way is to aspirate gastric contents and place the contents on pH/ indicator paper. The paper will turn color to indicate the pH. Another way is to continually monitor pH levels with an indwelling pH probe. Should the stomach pH indicate excessive acidity, alkalinization of gastric contents can reduce the incidence of stress ulceration. This can be done two ways, either by installation of topical antacids through the nasogastric tube itself or by use of parenteral histamine H2 receptor antagonists. In the latter method, the drugs reduce the volume of gastric juice secreted and also reduce the hydrogen ion concentration of the gastric contents, raising pH.

Esophageal Tubes

Esophageal tubes help control hemorrhage from esophageal or gastric varices. The Sengstaken-Blakemore, Linton and Minnesota tubes are characterized by balloons that can be inflated in the esophagus and/or stomach to compress the bleeding site. The inflated balloons also help keep the tubes in place. Multiple lumens at the proximal end of the tubes allow access to balloons, gastric irrigation and suction.

The tube can be inserted through either a nostril or through the mouth. After insertion, the balloons are carefully inflated: the inflation pressure of the balloons can be monitored with a manometer. The tube is usually attached



Helmet Support of Esophageal Tube
Figure 25

to traction, provided by either a traditional traction frame, ropes and pulleys or by attachment to the face guard of a football helmet placed on the patient's head (Figure 25).

These tubes are recommended for short-term use of no more than 48 hours. Even within this limited time period, clinicians need to be vigilant. If the balloons remain inflated for longer than 24 hours, the risk of pressure on the esophageal wall or gastric mucosa can cause necrosis and lead to additional bleeding or, in some cases, perforation.

Airway occlusion can occur if the tube advances into the pharynx or is misplaced into the trachea. Consequently, patients with these tubes should be under constant observation. If a patient has esophageal varices, esophageal rupture is a possibility since varices weaken the esophageal wall.

Nasoenteric (Intestinal) Tubes

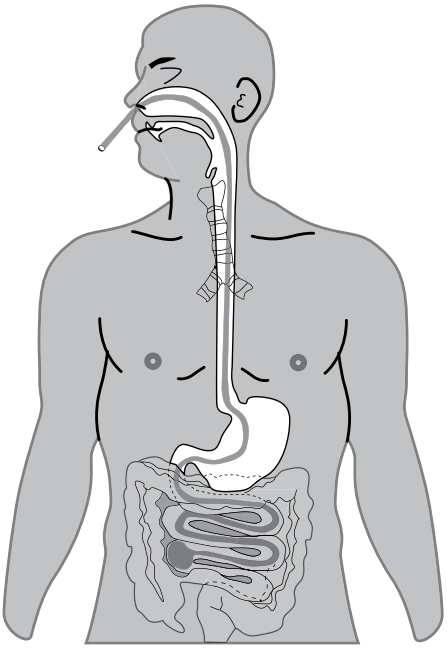
Nasoenteric or intestinal tubes used primarily for intestinal decompression help prevent nausea, vomiting and postoperative abdominal distention. They also provide aspirated intestinal contents. The tube is initially inserted through the nose into the stomach in the same way a nasogastric tube is placed. Usually radiopaque, these tubes have a balloon filled with mercury, air or water at the distal end. The balloons add weight and facilitate movement into the small bowel. A gauze sling on the patient's forehead supports the tube, but does not fix it in place because normal peristaltic movements will advance the tube through the pylorus and into the small bowel. To facilitate this movement, the patient should lie on his right side. X-rays can be used to confirm the tube's position. Once the tube has reached the specified location, the tube is taped to the nose (like a nasogastric tube) to prevent further advancement into the small bowel. Markings on the tube are monitored to detect movement.

Cantor Tube

The Cantor tube is a single-lumen tube much like a long Levin tube, with a latex balloon at the tip (Figure 26). Mercury is usually added to this balloon before the tube is inserted through the nose. After the tube reaches the stomach, the weight of the mercury and the size of the balloon facilitate passage of the tube by peristalsis.

Miller-Abbott Tube

The double-lumen Miller-Abbott tube is ten feet long. One lumen is used for instilling a balloon at the distal tip with mercury, water or air while the other lumen allows for drainage of intestinal contents (Figure 26). Initially, all the air is withdrawn from the balloon to facilitate passage of the tube through the nose. Once the tube is properly placed in the stomach, the distal balloon is filled to facilitate movement through the pylorus.



Cantor or
Miller-Abbott Tube
Figure 26

Care of Nasoenteric Tubes

Patients with nasoenteric tubes require the same type of comfort care as patients with nasogastric tubes. The tubes are usually attached to suction devices. To assess positioning, aspirated contents can be tested for pH. A pH less than 7.0 (acidic) indicates that the contents have come from the stomach; greater than 7.0 (alkaline) indicates that the contents have come from the intestines. As with gastric tubes, patient monitoring includes assessment of

the color, consistency and amount of drainage from the nasoenteric tube. Fluid intake and output and electrolytes should be monitored as well. Presence of active bowel sounds, flatus and decreased abdominal distention may be indications that the tube is no longer required.

Removal of Nasoenteric Tubes

If the patient has a double-or triple-lumen tube, the balloon should be deflated before the tube is removed. The material in the balloon (air, water or mercury) of a single-lumen tube will be removed after the tube is removed from the patient. After the tape is removed, the tube is withdrawn from the patient at a distance somewhere between two and eight inches (depending on hospital policies and procedures) every 10 minutes, until the distal end of the tube reaches the esophagus. At this point, about 18 inches of tube remain in the patient. The rest of the tube can then be removed quickly.

If the tube has moved past the ileocecal valve, it may be difficult to withdraw. The physician will determine whether the tube can be cut where it leaves the body at the nose and allowed to pass out of the body through the rectum.

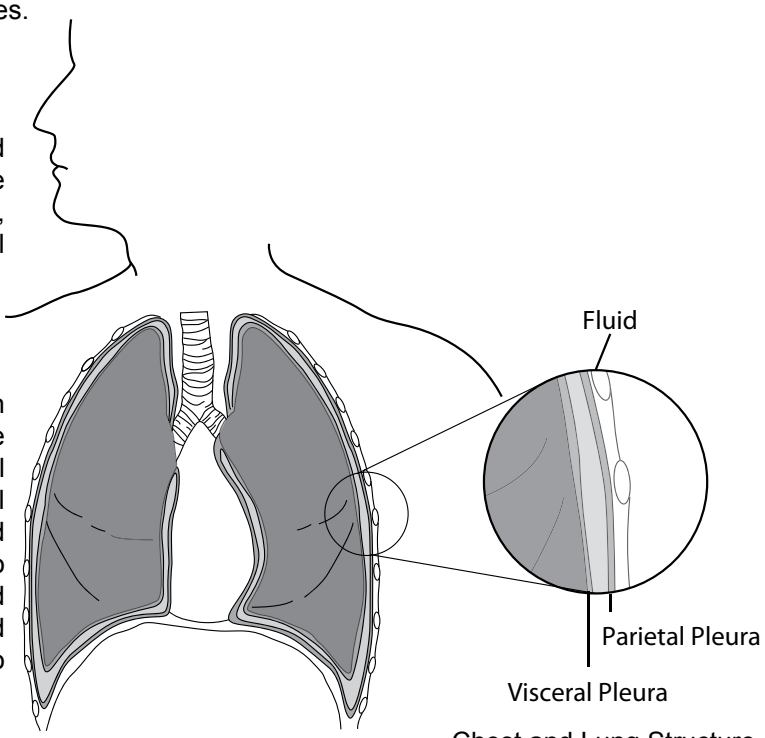
If the tube's balloon was inflated with mercury, the mercury must be handled as hazardous waste and disposed of in accordance with hospital policies and procedures.

Pleural Drainage

A chest tube is simply a drain that removes blood and/or other fluids from the body cavity. Because lungs contain air, there may be air in the plural space, a drain in the chest must be able to drain air as well as fluid.

Anatomy and physiology

The chest cavity is lined with the parietal pleura, which is adjacent to the visceral pleura, the covering of the lung (Figure 27). Because the parietal and visceral pleural surfaces are normally in contact, the pleural space between them contains a small amount of fluid to lubricate the surface and to allow the pleurae to easily slide over each other as the lungs expand and contract with breathing. The presence of pleural fluid creates surface tension, which helps keep the two pleural surfaces together.



Chest and Lung Structure
Figure 27

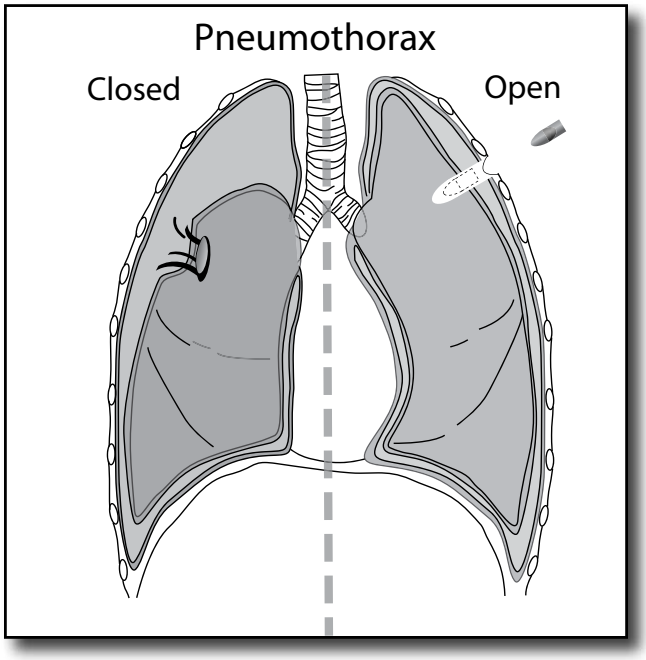
When the thoracic cavity expands to a greater volume, negative pressure is created in the chest. Since the pleura lining the thoracic cavity and covering the lung normally remain in contact, pressure changes that expand the thoracic cavity will expand the lungs as well. Air or fluid in the pleural space can result in lung collapse because negative pressure between the pleurae is lost, and either part or all the lung is no longer affected by changes in the size of the thorax.

Chest Tube indications

There are basically three conditions treated with chest tubes: a pneumothorax, a pleural effusion and a hemothorax. Air in the pleural space causes a pneumothorax; fluid in the same area causes a pleural effusion, and blood in the pleural space causes a hemothorax.

Pneumothorax

There are two types of pneumothorax: an open pneumothorax and a closed pneumothorax (Figure 28). An open pneumothorax occurs when both the chest wall and one of the lungs have been penetrated. Perforation can be caused by trauma such as stab and gunshot wounds, impaled objects, or incisions made during thoracic surgery. Open pneumothorax is often referred to as a “sucking chest wound”.



Closed and Open Pneumothorax
Figure 28

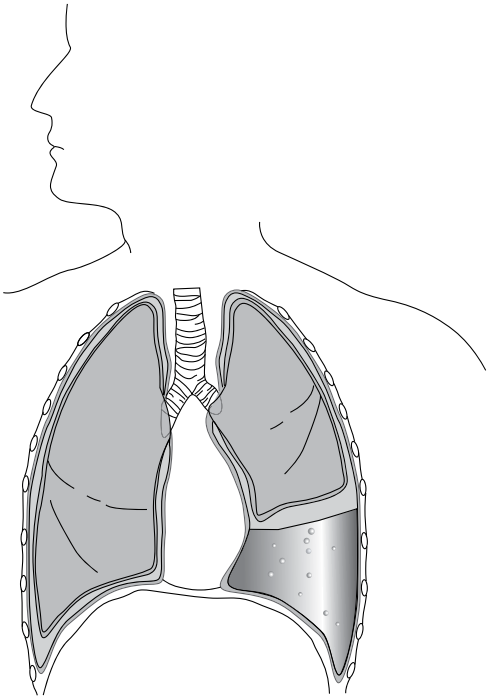
Closed pneumothorax results from a rupture of the lung tissue and the chest wall remains intact. It occurs when rapid deceleration tears lung tissue or when sharp bone edges from rib fractures tear the delicate lung parenchyma. A closed pneumothorax can also happen when patients with emphysema rupture already damaged air sacs while coughing or when intubated patients are ventilated with high pressures that rupture damaged lung tissue.

A tension pneumothorax is a special type of closed pneumothorax. It occurs when air in the pleural cavity accumulates under pressure and cannot escape. If this excessive pressure is not relieved, the lung on the affected side will completely collapse. The pressure will then be transmitted to the mediastinum. In the worst case, pressure surrounding the heart prevents it from expanding to accept venous return. Diminished venous return will lead to decreased cardiac output, resulting in cardiovascular collapse and cardiac arrest. Even CPR won’t be effective because if the heart can’t expand to accept venous blood, there will be no blood to pump out with compressions. Patients at greatest risk for tension pneumothorax are patients receiving positive pressure ventilation. Immediate treatment consists of insertion of a large bore needle in the chest to relieve the pressure, followed by placement of a chest tube.

A tension pneumothorax most often occurs only with closed pneumothorax. An open pneumothorax provides a “pressure relief valve” because the pressure is vented through the opening in the chest wall. A chest tube essentially converts a closed pneumothorax to a less risky open pneumothorax. Obstruction of the chest tube with lung tissue can turn an open pneumothorax into a tension pneumothorax.

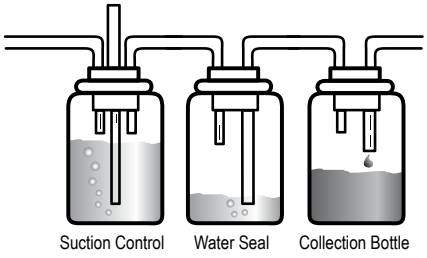
Pleural effusion and hemothorax

Fluid in the pleural space will compromise respiratory function in much the same way that air in the pleural space does. Pleural effusion refers to serous fluid that can accumulate post-operatively or from inflammatory effusions seen with pleurisy or diseases such as cancer (Figure 29). Blood (hemothorax) in the pleural space can accumulate from trauma or post operatively following chest surgery.

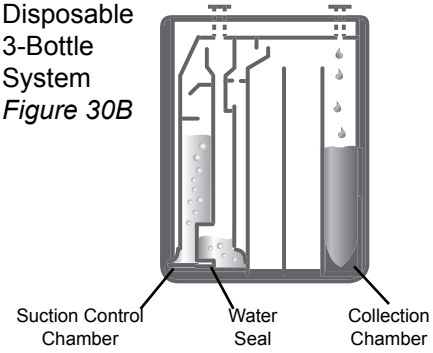


Pleural Effusion
Figure 29

Reusable 3-Bottle System
Figure 30A



Disposable 3-Bottle System
Figure 30B



Chest drainage devices

A chest tube, placed to remove air or fluid from the chest, will be connected to a drainage device (Figure 30). The original systems consisted of three glass bottles.

1. A collection bottle placed closest to the patient (in sequence), collects fluid draining from the chest.
2. A bottle with a water seal provides a one-way valve that allows air to vent and at the same time prevents air from re-entering the chest. The presence of bubbles in the water seal bottle indicates an air leak in the system or the lung.
3. The suction control bottle which contains a tube submerged in water or saline. The level of fluid in this bottle regulates the maximum amount of negative pressure that can be applied to the pleural space. With the suction source attached to the bottle, the level of negative pressure is gradually increased until gentle bubbling begins. The bubbling indicates that excess negative pressure is being vented to atmosphere.

These three bottle systems have been replaced in many institutions by disposable plastic boxes that provide chambers instead of the bottles. However, the function of each remains the same. When using the chest drainage system, pressure is regulated at the chest drainage system itself and the vacuum regulator in the wall is used to “power” the system. Manufacturers of chest drainage systems recommend a pressure for the wall regulator (usually 80 mmHg) and must be followed to avoid patient injury.

Another chest drainage device replaces the chest drainage system with a one-way flutter valve called the Heimlich valve. This device serves the same function as the one-way valve of the water seal bottle or chamber, but provides no indication of air leaks. The Heimlich valve is most commonly used for patients with simple pneumothorax or for transport since it was initially designed for combat use to treat chest wounds in the field during the Vietnam War.

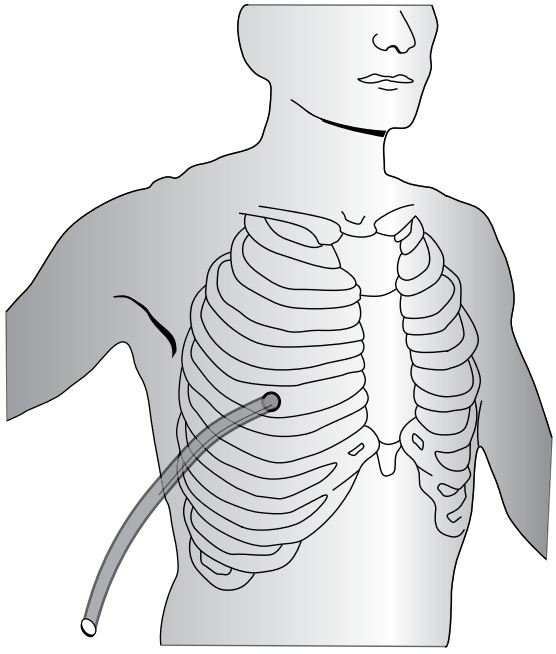
Chest tube insertion

The chest tube is placed in the pleural cavity by a surgical procedure, often done at the bedside. The tube is commonly placed in the fourth intercostal space in the mid-to anterior-axillary line (Figure 31). After making a small incision over the inferior rib, blunt dissection is done with a blunt-tipped hemostat The clamp is advanced up and over the rib, into the pleural space. This creates an oblique passage that will collapse and seal after the chest tube is removed. The tube is inserted through the tract alongside the clamp, and advanced into the chest.

After lung surgery, two tubes are generally placed in the pleural space; one is located anteriorly to evacuate air, and the other is located posteriorly to drain fluid.

A chest x-ray must be taken and examined to ensure correct chest tube placement. Two analyses are necessary:

1. The location of the tube is noted.
2. The radiograph is examined to determine whether the problem has been resolved (i.e. whether the pneumothorax has been cleared or whether fluid accumulation in the chest has been reduced and the lung re-expanded).



Placement of Chest Tube
Figure 31

Clamping chest tubes

For many years, it was universally taught that large clamps should accompany a chest tube system. These clamps were to be applied to the chest tube if a bottle broke or while moving the patient from one place to another. This is now considered an outdated practice. If a chest drainage bottle or system is broken or disconnected, the patient will have an open pneumothorax. The pneumothorax can be corrected by dropping the exposed end of the chest tube into a container of sterile fluid, water or saline. The tube should be submerged to a depth of 2 to 3 centimeters. This will allow the chest tube to function normally and provide a one-way valve while a new chest drainage system is set up. The tubing to the suction source should be disconnected and left open.

Clamping the chest tube in the presence of an air leak can be harmful. It will convert an open pneumothorax to a more risky closed pneumothorax. Clamping the tube in the presence of an air leak has produced tension pneumothoraces. Patients should be transported without clamping the chest tube.

Chest tube removal

With gradual reduction of the air leak the patient should be evaluated for removal of the chest tube. Most often the suction is removed and the patient is observed for 24 hours. If the removal of suction is well tolerated and chest X-ray does not show evidence of pneumothorax, the chest tube can be removed. After the dressing is removed, any sutures tying the chest tube to the skin are cut. The patient is told to breathe in deeply and strain, as if lifting a heavy object, performing a Valsalva maneuver (exhaling against a closed glottis). Since the pressure in the pleural space is positive during the Valsalva maneuver, the tube can be safely removed without air entering the pleural space. An occlusive dressing is placed over the insertion site as the tube is removed. A chest x-ray should be obtained and examined immediately after chest tube removal to assure that no air has entered the pleural space.

The use of pleural suction

Nearly all chest drainage systems are connected to suction. Pleural suction is usually supplied by a wall vacuum regulator or a fan-driven, high flow electric pump, Applying suction to the chest drainage system increases the flow rate at which air is removed from the chest. Quick removal of air is especially important for patients receiving positive pressure ventilation to prevent air from accumulating in the pleural cavity despite the chest tube.

Pleural suction usually ranges from 10 to 20 cm H_2O negative pressure. This range is very low compared to the amount of negative pressure used in other clinical suction procedures. A pleural suction device should be able to handle a relatively large volume of air with minimal restrictions to air flow.

A pleural suction device should have a fail-safe default operation to ensure patient safety. If the device is turned off but not disconnected from the patient, the chest drainage system should automatically open to the atmosphere so that air can escape normally from the chest tube, chest drainage system, and ultimately the patient's chest. Not all systems providing pleural suction meet this requirement.

In standard suction regulators there is usually a needle valve to control the flow of air through the system. These are high-impedance, low-flow devices. They will generally not have sufficient capacity to evacuate large air leaks. The Ohio Medical Thoracic Suction Regulator is a completely different device, designed specifically for thoracic suction (Figure 31). This silent regulator converts source vacuum to suction in the range of 5-50 cm H_2O negative pressure, with low impedance and high-flow capability. The regulator is designed to be plugged into a wall vacuum outlet. A large knob and dial on the front panel allow easy adjustment of the amount of suction. The on/off wheel in back is designed with patient safety in mind. When the regulator is turned off, a port opens to the atmosphere to vent the system. A built-in pressure relief valve decompresses transient positive pressure that may be generated when the patient coughs. In addition, this relief valve is an important safety device by minimizing the risk of tension pneumothorax if air builds up in the chest, or if there is an occlusion distal to the regulator. No positive pressure relief valve can work if an occlusion, such as a kinked tube or clamp is between the patient and the device. The device is compact, and can be mounted out of the way of medical personnel and the patient.

The fan-operated device works on a different principle from wall regulators. A large fan is driven by a potentiometer-controlled motor. The input port of the fan provides suction. A gauge indicates the level. Because the fan is a low-impedance, high-capacity device, these units are useful even for large air leaks. When the unit is turned off, air escapes through the space between the fan blades. Although the device has low-impedance and is fail-safe, it is also large, cumbersome, and noisy and takes up considerable space at the bedside.

Appendix A

AN EQUATION FOR THE FLOWRATE OF FLUID THROUGH A TUBE CAN BE WRITTEN FROM POISEUILLE'S LAW AS FOLLOWS:

$P \times 3.14 \times r^4 \div 8 \times \eta \times \int = \text{Flowrate}$

Where:

P is pressure
η the viscosity of the fluid
r the radius of the tube
$\int$ is the length of the tube
8 and 3.14 are constants

ORIGINAL EXAMPLE:

Pressure = 100
Radius = 2
Viscosity = 1
Length = 50

(*Relative numbers are used for illustration purposes)

100 x 3.14 x 16 ÷ 8 x 1 x 50 = Flowrate of 12.56

(100 is the pressure applied to the tube, 3.14 is a constant, 16 is the fourth power of the tube's radius (which is 2), 8 is a constant, 1 is the viscosity of the fluid, and 50 is the length of the tube)

THE EFFECT OF INSIDE TUBE DIAMETER ON FLOWRATE:

If we go back to the **ORIGINAL EXAMPLE** leaving all parameters the same but we double the diameter from 2 to 4, the new flowrate will be:

100 x 3.14 x 256 ÷ 8 x 1 x 50 = flowrate of 200.96

Notice that by doubling the diameter of the tube, the flowrate increased 16 times i.e. 12.56 x 16 = 200.96

If we cut the diameter in half in this case, the flowrate would drop to 1/16 of its original value.

THE EFFECT OF PRESSURE ON FLOWRATE:

If we go back to the **ORIGINAL EXAMPLE** leaving all parameters the same but we increase the pressure from 100 to 200, the new flowrate will be:

200 x 3.14 x 16 ÷ 8 x 1 x 50 = Flowrate of 25.12

Notice that by doubling the pressure in this case we doubled the amount of flow through the tube i.e. 12.56 to 25.12.

THE EFFECT OF FLUID VISCOSITY ON FLOWRATE:

If we go back to the **ORIGINAL EXAMPLE** leaving all parameters the same but we increase the viscosity from 1 to 3, the new flowrate will be:

100 x 3.14 x 16 ÷ 8 x 3 x 50 = 4.19

In this case the flowrate dropped from 12.56 to 4.19 as a result of increased fluid viscosity. A practical example of this is observed when suctioning thick bronchopulmonary secretions. Thicker secretions move slower through the catheter.

THE EFFECT OF TUBE LENGTH OF ON FLOWRATE:

If we go back to the **ORIGINAL EXAMPLE** leaving all parameters the same but we increase the length from 50 to 75, the new flowrate will be:

100 x 3.14 x 16 ÷ 8 x 1 x 75 = 8.37

Notice that increasing the length of the tube dropped the flowrate from 12.56 to 8.37. Decreasing the length of the tube would have the opposite effect and increase the flowrate.

APPENDIX B

1 inch of water (in H_20)
= 0.074 inches of mercury (in Hg)
= 0.036 pounds/square inch (psi)
= 1.87 millimeters of mercury (mmHg)
= 2.54 centimeters of water (cm H20)

1 centimeter of water (H20)
= 0.029 inches of mercury (in Hg)
= 0.014 pounds/square inch (psi)
= 0.74 millimeters of mercury (mmHg)
= 0.394 inches of water (in H_2O)

1 atmosphere (atm)
= 14.7 pounds/square inch (psi)
= 760 millimeters of mercury (mmHg)
= 29.92 inches of mercury (in Hg)

1 inch of mercury (in Hg)
= 25.4 mmHg
= 34.5 cm H_2O
= 13.6 in H_2O

1 millimeter of mercury (mmHg)
= 0.039 inches of mercury (in Hg)
= 0.019 pounds/square inch (psi)
= 0.535 inches of water (in H20)
= 1.36 centimeters of water (cm H20)

1 cm = 10 mm
1 torr = 1 millimeter of mercury
mmHg x O. 13332 = KPa
mmHg x 1.3332 = Millibar
mmHg x 1.3595 = cm H20
cm H20 x 0.7355 = mmHg
KPa x 7.5006 = mmHg
Millibar x 0.75006 = mmHg

Pressure Unit Conversion Constants

		Desired Value					
	PSI(1)	In $_H2O$(2)	In Hg(3)	K Pascal	milli Bar	cm H_2O(4)	mmHg(5)
PSI(1)	1.000	27.680	2.036	6.8947	68.947	70.308	51.745
In H_2O(2)	3.6127×10^{-2}	1.000	7.3554×10^{-2}	0.2491	2.491	2.5400	1.8683
In Hg(3)	0.4912	13.596	1.000	3.3864	33.864	34.532	25.400
K Pascal	0.14504	4.0147	0.2953	1.000	10.000	10.1973	7.5006
milli bar	0.01450	0.40147	0.02953	0.100	1.000	1.01973	0.75006
cm H_2O(4)	1.4223 c 10^{-2}	0.3937	2.8958×10^{-2}	0.09806	0.9806	1.000	0.7355
mmHg(5)	1.9337×10^{-2}	0.53525	3.9370×10^{-2}	0.13332	1.3332	1.3595	1.000

Known Value

To convert a value, multiply the known value from the first column by the table entry to get the desired value from the first row.

Example: 50 cm H_20 x 0.7355 = 37 mmHg

Notes:

1. PSI - pounds per square inch
2. at 39°F
3. at 32°F
4. at 4°F
5. at 0°F

APPENDIX D

CATHETER SIZE CHART*

Recommended French catheter size for given artificial airway size in mm internal diameter

Internal diameter artificial airway size in millimeters	Recommended French Size for Catheter (Adults: ETT inside diameter in mm x 3 ÷ 2 Infants: ETT inside diameter in mm x 3 ÷ 1.5
2.5	5.0
3.0	6.0
3.5	6
4.0	8.0
4.5	8.0
5.0	8.0
5.5	8.0
6.0	10.0
6.5	10.0
7.0	10.0
7.5	12.0
8.0	12.0
8.5	12.0
9.0	14.0
9.5	14.0
10.0	14.0

* Clinical Practice Guidelines Respiratory Care; June 2010 Vol. 55 No 6.21

APPENDIX E

The following tables are included with permission from AMERICAN SOCIETY FOR TESTING AND MATERIALS, 1916 Race SI., Philadelphia, PA 19103, (215) 299-5400, Designation F 960-86 (93), Standard Specification for MEDICAL AND SURGICAL SUCTION AND DRAINAGE SYSTEMS, approved 8 Jan. 1986, reviewed 1993, Reprinted from the Annual Book of ASTM Standards, Copyright ASTM.

X1. LUMEN (PASSAGEWAY) SIZE AND ITS EFFECTS ON FLOW

X1.1 The laminar flow of fluid (gas or liquid) is approximately proportional to the fourth power of the inside diameter (10) to the lumen, and inversely proportional to the length.

X1.2 For each system setup it is suggested that the largest diameter and shortest tube practical should be used.

X1.3 Table X1.1 shows the relative flow rates of various sizes of straight tubing under similar conditions. The flow through a 6.35 mm (1/4 in.) ID tube is designated as 100%.

TABLE X1.1 Relative Flow Rates of Straight Tubing

Diameter In (mm)	Flow %	Estimated Pressure Drop for 2m (6ft) Length. MmHg[A]	Approximate Water Flow (L/min) through 2m (6ft) Length[B]
3/16 (4.76	30	47	2.7
(5)	40	39	3.2
7/32 (5.56)	60	25	4.0
(6)	80	19	4.7
¼ (6.35)c	100	15	5.5
(7)	150	10	6.2
9/32 (7.14)	160	8	6.5
5/16 (7.94)	240	5	7.7
(8)	250	4.8	7.8

[A] Estimated vacuum Loss per 2m (6ft) length of straight tubing flowing 20 L/min air at a source vacuum of 300 rnm Hg. Specific brands of tubing may give slightly different results depending on smoothness of lumen and properties of material.

[B] These flow rates are for horizontally positioned tubing at ambient temperature and an applied vacuum of 300 mmHg.

[C] Suggested minimum diameter.

X2. MINIMUM AND MAXIMUM FREE AIR FLOW RATES AND VACUUM LEVELS FOR SUCTION AND DRAINAGE

X2.1 The committee felt the flow rates and vacuum levels for the types of procedures given in Table X2.1 may be experienced in clinical practice. Systems and their components should be selected to provide appropriate performance capability. Performance disclosure should help in making this selection.

TABLE X2.1 Air Flow Rates and Vacuum Levels[A]

Type of Procedure	Static Vacuum Level	Flow Rate, L/min
Infant Oral-Nasal Tracheal Suction	0-100 mmHg	0-40
Adult Oral-Nasal Tracheal Suction	0-160 mmHg	0-40
Surgical Suction	0-500 mmHg	0-40
Gastrointestinal Abdominal Drainage	0-120 mmHg	0-8
Wangensteen Drainage	0-60 mmHg	0-3
Wound Drainage	0-95 mmHg	0-2
Pleural or Mediastinal Drainage	0-50 cm H20	0-10
Pleural or Mediastinal Drainage(Pediatric)	0-10 cm H20	0-8
Nasal-Gastric Drainage	0-120 mmHg	0-3
Sump Drainage	0-50 mmHg	0-3

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